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PLAIN CONCRETE

PLAIN CONCRETE

BY

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PREFACE

A number of engineering colleges are now offering undergraduate courses in plain concrete and it is primarily to meet the needs of these classes that this volume has been prepared. Practising engineers should also find it of value in the preparation of specifications, in the supervision of construction work and in the testing of concrete and concrete materials.

The requirements of a college course in plain concrete call for a combination textbook and laboratory manual. This book being prepared for such use contains first material discussing the fundamental problems of concrete production and then instructions for the performance of laboratory tests.

In the text portion concrete materials are considered first. Methods of production are discussed briefly with special emphasis on items which affect the quality of the concrete in which they may be used. Purposes and values of the various tests are treated and specifications of the American Society for Testing Materials quoted wherever available. Following the discussion on materials the problems of proportioning, making, placing, finishing and curing of concrete are considered. Other subjects covered are: field control methods, high-early-strength concrete, workability, waterproofing, estimating quantities of materials, specifications for concrete construction, sampling and testing.

In the laboratory portion, instructions are given for the performance of all the usual tests on cement and aggregates, and for a number of research problems on concrete suitable for class use. Methods of testing prescribed by the American Society for Testing Materials are followed wherever available. The author has rearranged the instructions in such a way that the student can follow the operations in consecutive order, thus greatly facilitating the work in the laboratory. Forms are also given for the recording of laboratory data.

The author wishes to express his grateful appreciation to the many individuals, firms, and associations that have contributed information and pictures for use in this volume.

EDWARD E. BAUER.

URBANA, ILLINOIS,
October, 1928.

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PLAIN CONCRETE

CHAPTER 1

INTRODUCTION

Concrete is a mixture of a cementing material and a mineral aggregate. Cementing materials may be divided into two general classifications, bituminous and non-bituminous. Asphalts and tars compose the group of bituminous cements and portland cement, aluminate cement and natural cement make up the non-bituminous group. The mineral aggregate may be either crushed rock, gravel, slag, cinders or burned shale.

Due to the wide use of portland cement as the cementing material, the word concrete usually means portland cement concrete. When the meaning is not clear, the kind of cementing material used should be designated, as portland cement concrete or asphaltic cement concrete. Occasionally it is desired to designate the kind of aggregate used and then the words indicating the kind of cement are omitted. Crushed stone concrete or slag concrete are examples. The type of aggregate is usually designated only when slag, cinders or burned shale are used.

This book deals largely with portland cement concrete since portland cement is the non-bituminous cementing material most used. Natural cements are still produced but are not used extensively in concrete. Aluminate cement has been available on the American market since 1925, but the production has not been large as compared with that of portland cement. Aluminate cement concrete gains strength much more rapidly than does portland cement concrete, but the selling price of aluminate cement is higher, being about three to four times that of portland cement. Some discussion of aluminate cement and aluminate cement concrete is given in Chaps. 3 and 11.

History of Cement

The use of cementing materials dates back several thousand years. The early Romans and Egyptians used a variety of

mortars and mortar-making materials.[1] Remains of some early structures indicate the quality of the mortar used was good. No evidence is available, however, as to its composition or to the method of manufacture.

Natural Cement.—Natural cement is made by burning at a temperature between 1000 and 1300°C. a limestone containing a certain amount of shale or clay. The limes and cements used previous to the building of the Eddystone Lighthouse in 1756 by John Smeaton, a noted British engineer, were not capable of

FIG. 1.—Reinforced-concrete replica at Nashville, Tennessee, of the Athenian Parthenon.

setting under water.[2] Smeaton developed a cement which would set under water and, at the same time, contributed a valuable idea that the hydraulic properties of a limestone depended upon the percentage of clay in its chemical composition, and not upon its color and texture, as had been formerly supposed.

About 1791, Joseph Parker took out a patent for the production of a cement which he called Parker's cement. This later on became known as Roman cement. Parker had found certain rock deposits containing the proper elements necessary for the manufacture of an hydraulic cement.

[1] LESLEY, "History of the Portland Cement Industry in the United States," p. 1.

[2] LESLEY, "History of the Portland Cement Industry in the United States," p. 12; DAVIS, "A Hundred Years of Portland Cement," pp. 13–24.

M. Vicat, the noted French engineer, introduced in 1818 an hydraulic lime, which, he said, was composed of ground chalk mixed with the proper proportion of clay. A plant was established outside of Paris, but was not successful. Vicat was the first to experiment with the possibility of combining the raw materials in the production of cement. All cement produced

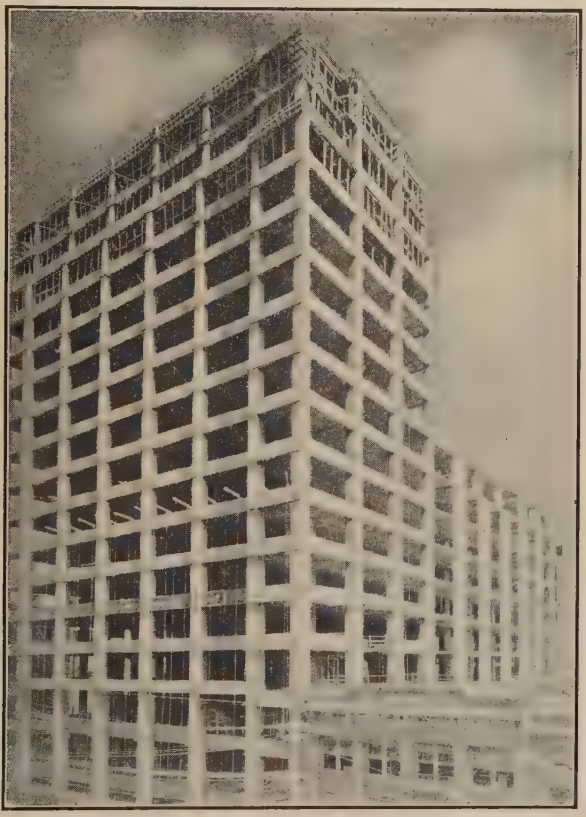


FIG. 2.—Reinforced-concrete skeleton for an office building.

prior to this time was made from a limestone containing sufficient clay.

The development of water transportation in the United States created a demand for cement and the natural result was the development of the industry in this country. The Erie canal was started in 1817 and the following year saw the beginning of the cement industry in the United States. Table 1 indicates

TABLE 1.—DISCOVERY AND EARLY USES OF NATURAL CEMENT IN THE UNITED STATES[1]

Year	Locality	Construction
1818	Fayetteville, N. Y.	Erie Canal
1824	Williamsville, N. Y.	Erie Canal
1826	Kensington, Conn.	Miscellaneous
1828	Rosendale, N. Y.	Delaware and Hudson Canal
1829	Louisville, Ky.	Louisville and Portland Canal
1831	Williamsport, Pa.	Muncy and Lock Haven Canal
1836	Cumberland, Md.	Miscellaneous
1837	Round Top, Md.	Cheasapeake and Ohio Canal
1838	Utica, Ill.	Illinois and Michigan Canal
1839	Akron, N. Y.	Miscellaneous
1848	Balcony Falls, Va.	Miscellaneous
1850	Siegfried's Bridge, Pa.	Easton and Mauch Chunk Canal
1850	Cement, Ga.	Miscellaneous
1863	Vallejo, Calif.	Miscellaneous
1867	Fort Scott, Kan.	Miscellaneous
1869	La Salle, Ill.	Miscellaneous
1869	Howe's Cave, N. Y.	Miscellaneous
1874	Buffalo, N. Y.	Miscellaneous
1875	Milwaukee, Wis.	Miscellaneous
1881	Canon City, Colo.	Miscellaneous
1893	Mankato, Minn.	Miscellaneous

[1] LESLEY, "History of the Portland Cement Industry in the United States," p. 32.

that much of the early natural cement was produced for the construction of canals.

Portland Cement.—To Joseph Aspdin, a bricklayer of Leeds, England, goes the credit for first producing portland cement. In 1824, he was granted a patent for his "improvements in the modes of producing an artificial stone." Aspdin called his new product *portland* cement because it resembled in color building stone found on the Isle of Portland. The original patent is very interesting and is quoted in full.[1]

A. D. 1824 No. 5,022

ARTIFICIAL STONE

Aspdin's Specifications

TO ALL TO WHOM THESE PRESENTS SHALL COME, I, Joseph Aspdin, of Leeds, in the County of York, Bricklayer, send greeting. Whereas His Present most

[1] DAVIS, "A Hundred Years of Portland Cement," pp. 33–37.

Excellent Majesty King George the Fourth, by His Letters Patent under the Great Seal of Great Britain, bearing date at Westminster, the Twenty-first day of October in the fifth year of His reign, did, for Himself, His heirs and successors, give and grant unto me, the said Joseph Aspdin, His special licence, that I, the said Joseph Aspdin, my exors., admors., and assigns, or such others as I, the said Joseph Aspdin, my exors., admors., and assigns. should at any time agree with, and no others, from time to time and at all times during the term of years therein expressed, should and lawfully might make, use, exercise, and vend, within England, Wales, and the Town of Berwick-upon-Tweed, my Invention of "An Improvement in the Modes of Producing an Artificial Stone": in which said Letters Patent there is contained a proviso obliging me, the said Joseph Aspdin, by an instrument in writing under my hand and seal, particularly to describe and ascertain the nature of my said invention, and in what manner the same is to be performed, and to cause the same to be inrolled in His Majesty's High Court of Chancery, within two calendar months next and immediately after the date of the said in part recited Letters Patent (as in and by the same), reference being thereunto had, will more fully and at large appear.

Now know ye, that in the compliance of the said proviso, I, the said Joseph Aspdin, do hereby declare the nature of the said Invention, and the manner in which the same is to be performed, are particularly described and ascertained in the following description thereof (that is to say):

Aspdin's Improvements in the Modes of Producing an Artificial Stone

My method of making a cement or artificial stone for stuccoing buildings, waterworks, cisterns, or any other purpose to which it may be applicable (and which I call Portland cement) is as follows: I take a specific quantity of limestone, such as that generally used for making or repairing roads, and I take it from the roads after it is reduced to a puddle, or powder; but if I cannot procure a sufficient quantity of the above from the roads, I obtain the limestone itself, and I cause the puddle or powder, or the limestone as the case may be to be calcined. I then take a specific quantity of argillaceous earth or clay, and mix them with water to a state approaching impalpability, either by manual labour or machinery. After this proceeding I put the above mixture into a slip pan for evaporation, either by the heat of the sun or by submitting it to the action of fire or steam conveyed in flues or pipes under or near the pan until the water is entirely evaporated. Then I break the said mixture into suitable lumps, and calcine them in a furnace similar to a lime kiln till the carbonic acid is entirely expelled. The mixture so calcined is to be ground, beat, or rolled to a fine powder, and is then in a fit state for making cement or artificial stone. This powder is to be mixed with a sufficient quantity of water to bring it into the consistency of mortar, and thus applied to the purposes wanted.

In witness whereof, I, the said Joseph Aspdin, have hereunto set my hand and seal, this Fifteenth day of December, in the year of Our Lord One Thousand eight hundred and twenty-four.

Joseph (L. S.) Aspdin

AND BE IT REMEMBERED, that on the Fifteenth day of December, in the year of Our Lord 1824, the aforesaid Joseph Aspdin came before our said Lord the King in His Chancery, and acknowledged the Specification aforesaid, and all and everything therein contained and specified, in form above written. And also the Specification aforesaid was stamped according to the tenor of the Statute made for that purpose.

Inrolled the Eighteenth day of December, in the year of our Lord One thousand eight hundred and twenty-four.

Aspdin's cement was, of course, not exactly as we have it today. Aspdin was not trained in chemistry and therefore could not proceed to develop his new discovery on a scientific basis. The major difference between Aspdin's cement and our portlands is in the burning. Aspdin calcined his raw material only until the carbonic acid was entirely removed. Today the raw materials are heated to incipient fusion.

I. C. Johnson, an English cement manufacturer, claims to be the real inventor of portland cement. Johnson was in charge of the works of J. B. White and Sons, and, in such capacity had the opportunity to experiment. On one occasion the raw materials were accidentally heated to semi-vitrifaction. Johnson decided to see what would happen if he pulverized this material. When made into a paste this material became very hard and had the color of the Portland stone. The set cement fell to pieces, however, when it was immersed in water. He said: "I was so ashamed at this signal failure that I had the product of the kiln hidden away in an isolated cellar or vault at the outskirts of the works near the river out of sight." Johnson, however, out of curiosity came back to the cellar in a few weeks and found that the damp atmosphere had acted upon the free lime present and had slaked it. Johnson then tried this material again and found that it hardened and did not disintegrate when immersed in water. Shortly following this experiment, in 1845, Johnson's company began the production of portland cement essentially as we have it today.

Introduction into the United States.—Portland cement was imported into this country first in 1865. European cement had acquired such a reputation for quality that it was difficult for American manufacturers to sell their product.

David O. Saylor, of Allentown, Pa., is generally given credit for being the first manufacturer of portland cement in this country.[1]

[1] LESLEY, "History of the Portland Cement Industry in the United States," p. 50.

He was granted a patent in 1871. The Coplay Cement Company, of which Saylor was the first president, shipped their first cement in 1874. Thomas Millen, of South Bend, Ind., and John

FIG. 3.—An old-time vertical kiln. This pioneer kiln used coke for fuel. The charge was arranged in alternate layers of coke and powdered rock made into bricks.

K. Shinn, of Wampun, Pa., were other pioneer manufacturers who produced their first cements about the time that Saylor produced his.

The quantity of cement produced each year has gradually increased until in 1927 over 173,000,000 bbl. were made. It is interesting to note that up until 1900, approximately the time of the adoption of a set of standard specifications, the amount of cement produced each year had not increased very rapidly. With the adoption and use of a standard specification the manufacturers were able to concentrate their efforts on quantity production and from 1900 to 1927 the production increased from 8,000,000 to 173,000,000 bbl.

About 1922 there was a shortage of cement. In the next few years a number of new plants were built and some of the old ones enlarged, so that the capacity of the mills in 1927 was about 200,000,000 bbl.

FIG. 4.—Lorado Taft's Fountain of Time at Chicago, Ill., was made with concrete.

Developments in the Manufacture.—The manufacturers of portland cement have ever been on the alert for the discovery of new methods to use in the production of their product. Their efforts have been for the most part to produce cement in greater quantities, resulting in lowered costs of production and lowered selling prices. Reduction in selling price has resulted in an increased volume of business. The quality of the cement was largely fixed by the user in his specifications.

Probably the most noteworthy development has been made in the burning process. The first cements were burned in intermittent vertical kilns. The development of a horizontal rotary kiln which could be operated continuously, meant much to the cement industry. The first British patent was issued to Thomas

Russell Crampton.[1] The first rotary kiln in this country was erected in 1896 at Roundout, N. Y., by Jose F. de Navarro and his two sons.[2] It was 24 ft. long and 12 ft. in diameter. In 1909, Thomas A. Edison was granted a patent for the use of kilns exceeding 150 ft. in length.[3] Today kilns vary in length from 150 to 343 ft. Inside diameters vary from 8 to 13 ft.

Particular attention is being paid now (1928) to the securing of more uniformity in the mixtures of raw materials which are prepared for burning in the kilns. Some manufacturers are mixing water with the limestone and shale to form a slurry, while others are securing the desired uniformity by means of blending bins where the dry materials are mixed or blended to the proper proportions of each. The former method is known as the wet process and the latter as the dry process. Most of the new plants being built now are for the wet process. The Olympic Portland Cement Company, Ltd., at Bellingham, Wash., was the first company to produce, in 1915, portland cement from hard raw materials by the wet process.[4]

Uses of Cement and Concrete

During the period since about 1900 the consumption of portland cement has been increasing (see Table 2 and Fig. 5) at the rate of about 10,000,000 bbl. a year up to and including 1927. This rapid increase has been brought about in part by finding new uses for cement and concrete. In 1902, the cement manufacturers formed an organization known as the Portland Cement Association, the purpose of which has been "to extend and improve the uses of portland cement," and to this association must go much of the credit for the development which has taken place. The public, too, has taken a natural liking to portland cement concrete and this has contributed much to increase the use of concrete. The public in its eagerness to find new uses for concrete has sometimes misused it. A few of the more important

[1] Davis, "A Hundred Years of Portland Cement," p. 163.

[2] Lesley, "History of the Portland Cement Industry in the United States," p. 109.

[3] Lesley, "History of the Portland Cement Industry in the United States," p. 123.

[4] Roberts, "The Pioneer Wet Process Cement Plant on the North American Continent," *Pit and Quarry*, p. 39 ff., Oct. 15, 1925.

TABLE 2.—CEMENTS PRODUCED AND IMPORTED INTO THE UNITED STATES AND AVERAGE FACTORY PRICE FOR YEARS 1890 TO 1927[1]

Year	Portland cement produced in United States, barrels	Portland cement imported, barrels	Average factory price, per barrel in bulk	Natural cements including Puzzolan, barrels
1890	335,500	1,940,186	2.09	7,441,116
1891	454,813	2,988,313	2.13	7,767,979
1892	547,440	2,440,654	2.11	8,211,181
1893	590,652	2,674,149	1.96	7,411,815
1894	798,757	2,638,107	1.73	7,563,488
1895	990,324	2,997,395	1.60	7,741,077
1896	1,543,023	2,989,597	1.57	7,982,715
1897	2,677,775	2,090,924	1.61	8,360,017
1898	3,692,284	1,152,861	1.62	8,651,924
1899	5,652,266	2,108,388	1.43	10,203,179
1900	8,482,020	2,386,683	1.09	8,749,130
1901	12,711,225	939,330	0.99	7,357,512
1902	17,230,644	1,963,023	1.21	8,522,860
1903	22,342,973	2,251,969	1.24	7,556,167
1904	26,505,881	968,409	0.88	5,169,376
1905	35,246,812	896,845	0.94	4,855,496
1906	46,463,424	2,273,493	1.13	4,537,021
1907	48,785,390	2,033,438	1.11	3,444,952
1908	51,072,612	842,121	0.85	1,838,313
1909	64,991,431	433,888	0.813	1,698,284
1910	76,549,951	306,863	0.891	1,235,190
1911	78,528,637	164,670	0.844	1,019,321
1912	82,438,096	68,503	0.813	913,095
1913	92,097,131	85,470	1.005	851,971
1914	88,230,170	120,906	0.927	819,596
1915	85,914,907	42,218	0.860	793,541
1916	91,521,198	1,836	1.103	842,137
1917	92,814,202	2,323	1.354	639,456
1918	71,081,663	305	1.598	432,966
1919	80,777,935	8,931	1.71	528,589
1920	100,023,245	524,604	2.02	767,481
1921	98,842,049	122,322	1.89	539,402
1922	114,789,984	323,823	1.76	889,428
1923	137,460,238	1,678,636	1.90	1,271,674
1924	149,358,000	2,010,936	1.834	1,418,464
1925	161,658,901	3,655,317	1.834	1,418,464
1926[2]	164,530,901	3,232,386	1.71	2,104,891
1927[2]	173,206,513	2,049,730		

[1] Data taken from various tables, LESLEY, "History of the Portland Cement Industry in the United States."

[2] Figures furnished by U. S. Dept. Commerce.

uses of concrete will be briefly explained in the following paragraphs.

Reinforced Concrete.—Reinforced concrete is concrete in which steel bars have been placed to take the tensile stresses, since concrete is comparatively weak in tension as compared to its compressive strength. Reinforced concrete is used

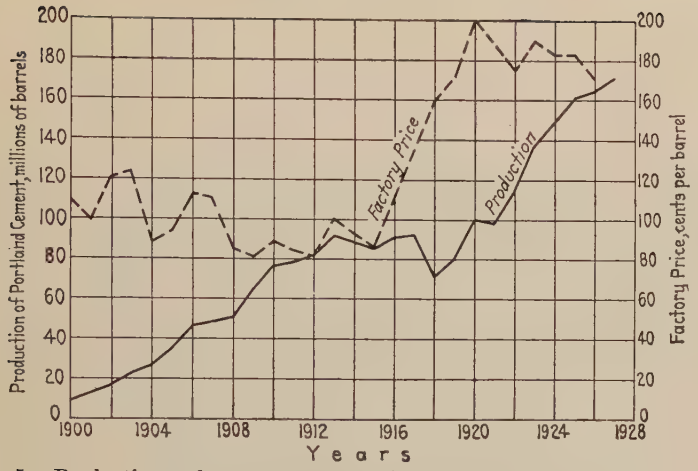
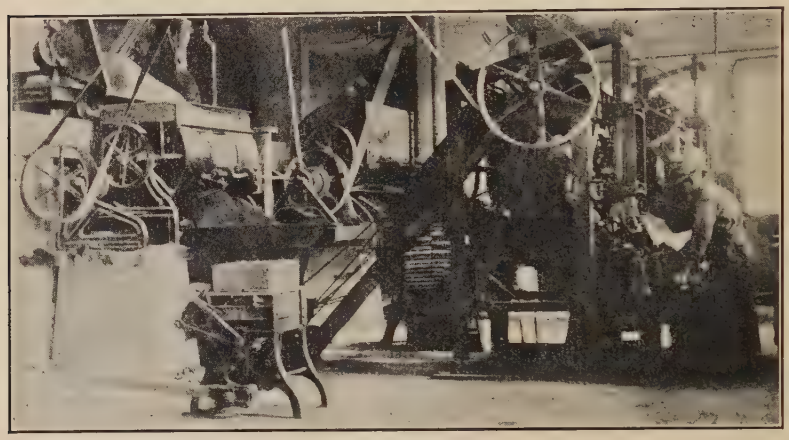


FIG. 5.—Production and average factory price of portland cement for the years 1900 to 1927.

FIG. 6.—Precast concrete blocks were used instead of cut stone for the exterior walls of the Portland Cement Association building in Chicago, Ill.

in the building of bridges, buildings, walls, floors, bins, reservoirs, etc.

Highway Construction.—In the period since the close of the World War the use of concrete as the wearing surface of pave-



(*a*) Making.

(*b*) Curing.

FIG. 7.—Manufacture of concrete products.

ments has greatly increased. There has been no general use of steel as a reinforcing material to take tensile stresses. Steel is used, however, to bond together the various parts of the slab when it cracks or has construction joints built in. Concrete is used also in constructing bases for other types of wearing surfaces,

the building of bridges, culverts, drains, curbs and gutters, and sidewalks.

Sewage Disposal.—Concrete is being used extensively in the building of sewage-disposal plants and in the construction of sewers and is of the reinforced type mentioned above.

Concrete Products.—The more important concrete products include building blocks, brick, sewer and drain tile, light standards, telegraph, telephone and electric wire poles, and fence posts. In order to remove the forms at once, the concrete is mixed to a relatively stiff consistency, which requires extra amounts of tamping, vibrating, or spinning. Light-weight aggregates are being used extensively in the building blocks.

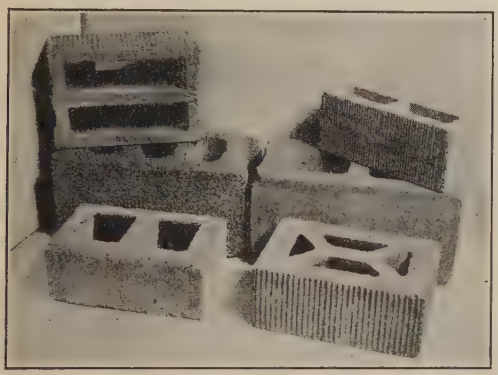


FIG. 8.—Various types of concrete building units.

Decorative Concrete.—Concrete is also being used in various ways to develop the decorative scheme of a building. One method is to use colored aggregates near the surface and to expose these aggregates within 24 hours by brushing away the mortar. Aggregates may also be exposed by grinding away the surface layer until the cross-section of the aggregate is shown. Any desired pattern may be executed with almost any combination of colors. Colored designs may also be painted on the surface of the concrete. For a discussion of the methods used see Chap. 8.

Cast Stone.—Another recent development is the making of solid blocks of concrete which resemble cut natural stone and which are handled and used in the same manner. The aggregates are not exposed and the cut stone effect is secured by the use of sand molds.

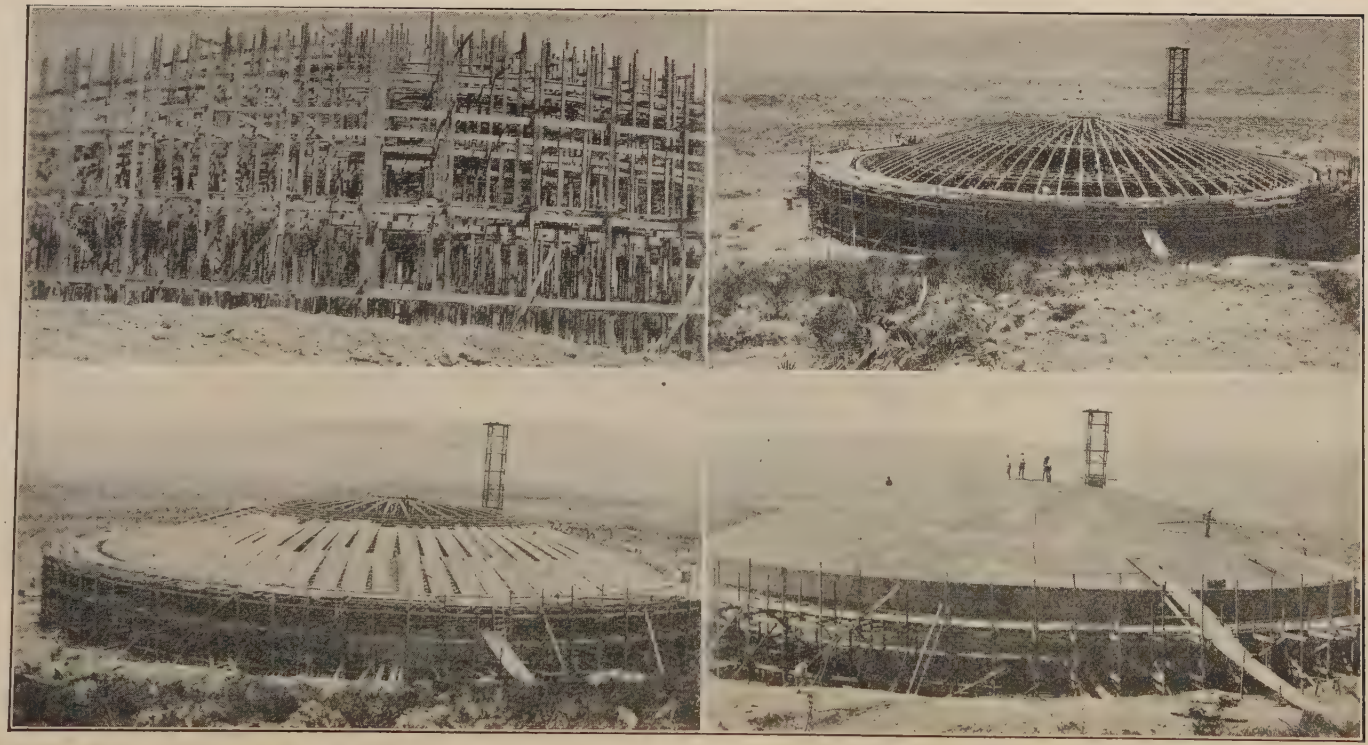
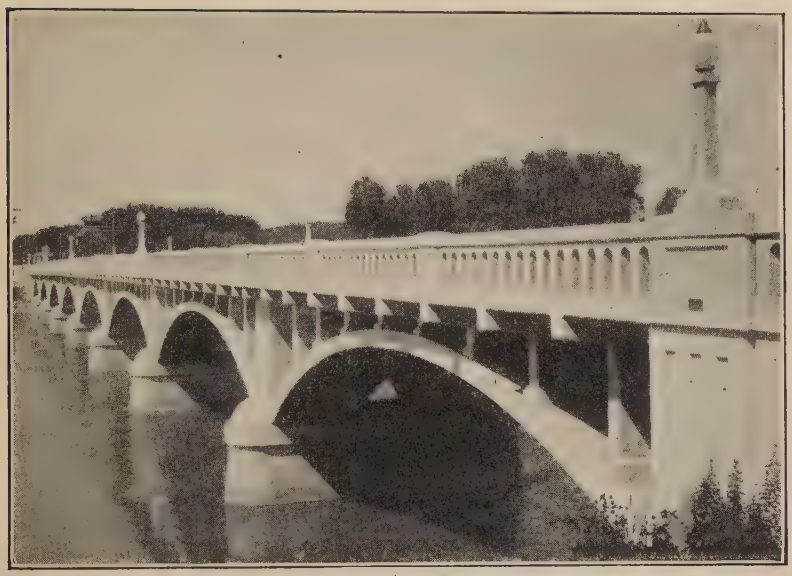


FIG. 9.—Reinforced-concrete tank with concrete dome under construction at El Paso, Tex. Capacity 2,300,000 gal. Used for storage of petroleum. Note large amount of form work.



(*a*)

(*b*)

FIG. 10.—Views of two reinforced-concrete bridges. (*a*) Highway bridge. (*b*) The Tunkhannock viaduct on the D. L. & W. R. R. which is nearly a half mile in length and is 240 ft. high.

Stucco.—Mixtures of cement and sand are now applied to the outside surfaces of walls of buildings. The aggregates may or may not show, the surface may be smooth or rough, and patterns may be worked in by molding the surface or by the use of aggregates. Stuccoed walls have a pleasing appearance and are durable.

Miscellaneous Uses.—Concrete is made to serve many other purposes around the home, on the farm, at the factory, in parks, etc.

Definitions

A few of the more common words and expressions used in connection with concrete will be explained or defined.

Portland Cement.—Portland cement is the binding material holding the mineral aggregate together.[1]

Aggregate.—Designated inert material, which when bound together into an agglomerated mass by a matrix forms concrete, mastic, mortar, plaster, etc. (From "Tentative Definitions of the Terms Sand and Aggregate" of the A. S. T. M., Serial Designation: C58-26T.)

Sand.[2]—The fine granular material (usually less than ¼ in. in diameter) resulting from the natural disintegration of rock, or from the crushing of friable sandstone rocks. (From "Tentative Definitions of the Terms Sand and Aggregate" of the A. S. T. M. Serial Designation: C58-26T.)

Fine Aggregate.—Fine aggregate is arbitrarily designated as that portion of the aggregate which will pass through a ¼-in. sieve.

Coarse Aggregate.—Coarse aggregate is arbitrarily designated as that portion of the aggregate which will not pass through the ¼-in. sieve.

Pebbles.—Pebbles are the naturally disintegrated particles of rock used as coarse aggregate in concrete.

Crushed Stone.—Crushed stone or rock are the artificially prepared particles of rock used as coarse aggregate in concrete.

[1] See p. 31 for complete A. S. T. M. definition.

[2] When used without a qualifying adjective, "sand" is generally understood to mean the product of the natural disintegration of siliceous or calcareous rock. Sand should be distinguished from screenings, gravel, etc. The size of the particle and other physical characteristics should be taken care of in specifications. The fine material resulting from the crushing of blastfurnace slag is known as "slag sand."

Blast-furnace Slag.—Blast-furnace slag is the non-metallic product consisting essentially of silicates and alumino-silicates of lime which is developed simultaneously with iron in a blast furnace.

Cinders.—Cinders are produced as waste material from steam boilers using bituminous coal.

Bank Gravel.—Bank gravel is the combination of sand and pebbles as found in the pit or bank.

Ready Mix Aggregates.—Sand and gravel producers often prepare at the pit mixtures of sand and gravel for sale by the dealers to users of small quantities of aggregate. The proportions of sand and gravel vary considerably and usually run high in sand content. Its use is not recommended for high quality concrete work.

Cement Paste.—Cement paste is the mixture of cement and water.

Mortar.—Mortar is the mixture of cement, water, and sand, as it occurs in concrete or as it is used in masonry work.

Grout.—Grout is also a mixture of cement, water, and sand, but the proportion of water is much greater. Grout is used principally as a filler in block types of pavements.

Concrete.—Concrete is the mixture of cement, water, and fine and coarse aggregates.

Water-cement Ratio.—Water-cement ratio is the ratio between the volume of mixing water used and the bulk volume of cement. European practice uses it as a ratio by weight.

Fineness Modulus.—Fineness modulus is a function of the grading of the aggregates based on the sieve analysis and is found by adding together the percentages coarser than the 100-, 48-, 28-, 14-, 8-, and 4-mesh and the $\frac{3}{8}$-, $\frac{3}{4}$-, and $1\frac{1}{2}$-in. square mesh Tyler sieves, and dividing by 100.

Cement-space Ratio.—The cement-space ratio is the ratio between the solid volume of cement and the volume of the cement paste. It is often written as the $\frac{c}{v + c}$ ratio, in which the c represents the solid volume of cement, and the v + c represents the volume of the cement paste.

Slump Test.—The slump test for consistency of concrete is made by first filling a truncated metal cone 12 in. high, 4 in. in diameter at the top and 8 in. at the bottom, with concrete, then removing the cone and noting the amount of settlement of the concrete. Slump test values are given in inches.

Hassam Concrete.—Hassam concrete is a patented type used only in building pavements. A layer of crushed stone at least 4 in. in thickness is laid first and then a 1:1 grout is flushed into the crushed stone. The grout normally penetrates to a depth of from 3 to 4 in. After the stone has taken all the grout possible, a thin layer of stone chips is spread over the surface and rolled until the grout comes through.

Vibrolithic Concrete.—Vibrolithic concrete is also used only in pavements. The method of laying the pavement is patented.

FIG. 11.—Finishing vibrolithic concrete. View shows wooden mats, vibrating machine, and crushed granite beyond mats. This pavement was built one-half at a time.

A layer of 1:2:4 concrete 6 to 7 in. in thickness is first laid and struck off as in the regular type. Then a layer of crushed granite or trap rock is spread over the surface. Wooden mats made of narrow slats are laid on the concrete and a vibrating machine run over the mats. The aggregate is settled and a layer of mortar is brought to the surface. The mortar is struck off and belted in the usual way.

Gunite.—Gunite is a mixture of cement, sand, and water applied by pneumatic pressure through a machine known as the "cement gun." The dry sand and cement which are mixed before being placed in the gun are carried in suspension in a hose by a stream of air to the nozzle where water is introduced

through a smaller hose. The amount of water can be regulated by a valve in the hand of the operator.

The usual mixes vary from a 1:2½ to a 1:5. Under ordinary conditions with the usual 1:3½ mix, the amount of water used per bag of cement is about 3½ gal. From 15 to 50 per cent of the sand, depending upon its characteristics, is normally wasted because it bounces back and drops to the ground. The percentage of *rebound* is higher with the coarse sands than with the finer ones.

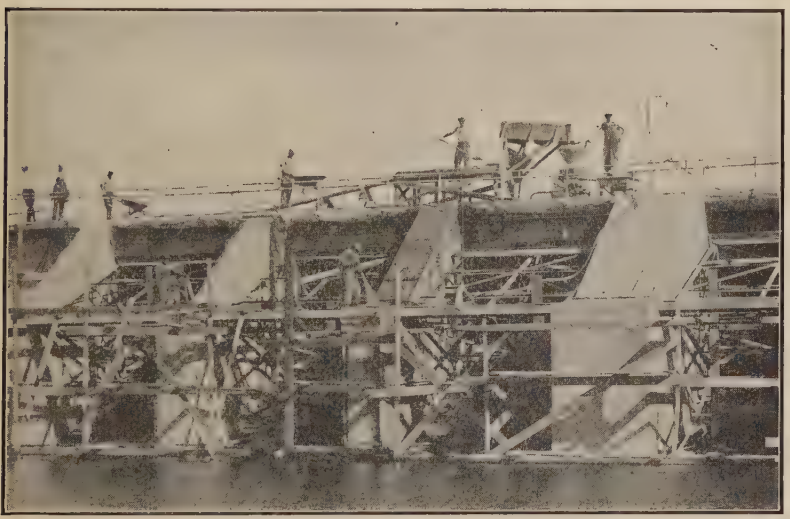


FIG. 12.—Typical gunite repair job. The soft surface of the old concrete has been chipped away to a depth of 2 in. Wire mesh reinforcing has been placed and fastened to the concrete with anchor bolts that extend in 4 to 5 in. Note the cement gun in operation at the center and the finished portion at the right.

The most common uses for gunite are for lining reservoirs; encasing steel, particularly on viaducts over railroad tracks; repairing disintegrated concrete structures such as dams, bridge piers and abutments, dry docks, lining coal bunkers, building baffle walls in Imhoff tanks and filter chambers, and building thin curtain walls on structural steel buildings.

It is difficult to give definite figures on the cost of gunite work because it varies considerably from job to job. For thicknesses of from 1½ to 2 in., the costs will vary from about 35 cts. to 80 cts. per square foot. The work shown in Fig. 12 was done for approximately 75 cts. per square foot.

Questions

1. What is concrete? portland cement concrete? pebble concrete? slag concrete?
2. When and where was portland cement first produced? By whom?
3. How did portland cement get its name?
4. Name various uses of portland cement concrete.
5. What is Hassam concrete? vibrolithic concrete? gunite?

CHAPTER 2

STANDARD PORTLAND CEMENT

Portland cement is produced by burning a mixture of limestone and shale to the point of melting and then grinding the resulting clinker to a very fine powder.[1] Gypsum is added during the grinding of the clinker for the purpose of retarding the setting action. Blast-furnace slag is substituted for the shale in several plants. Standard grey cements are those cements which are made in the usual way, and from the usual materials, and which meet the A. S. T. M. requirements for portland cement. Other cements made in a different way or from different materials and for special purposes are treated in the next chapter on Special Cements. Special cements include aluminate, high early strength portland, waterproof, and white cements. Cement is grey in color because of a small amount of iron oxide present.

Manufacture

Since the adoption of the first set of standard specifications by the A. S. T. M. in 1904, rapid strides have been made in the development of quantity production of portland cement. The price is remarkably low when one considers the amount of raw materials used and the care with which the various parts of the work is done. Important developments have been made in preparing the raw materials, burning, grinding and the recovery of heat which was formerly wasted. There is not much variation from plant to plant in the exact methods of manufacture.

Raw Materials.—The raw materials from which cement is manufactured are divided into two general classifications, argillaceous and calcareous. The most common combinations of these are:

Argillaceous	Calcareous
Shale or clay	Limestone
Cement rock	Limestone
Blast furnace slag	Limestone
Shale or clay	Marl

[1] For official A. S. T. M. definition, see p. 31.

Cement rock is a limestone, found principally in Pennsylvania, containing more than 50 per cent clay. Marl is a soft deposit of clay and calcium carbonate found in the bottoms of shallow lakes, swamps, or extinct fresh-water basins. Most of these deposits have been worked out so that there are very few marl cement plants operating today (1928).

FIG. 13.—General view in stone quarry from which limestone is secured.

PREPARATION OF RAW MATERIALS

The raw materials which are combined to produce portland cement must have the proper chemical constituents so that the finished product will have the proper physical and chemical requirements as given in the specifications (see page 32). The composition of the raw materials varies from place to place in the deposits, thus necessitating frequent analyses as the materials are removed. Tests are also made on the mixture before it is burned and adjustments made until the proper proportions of the various materials are secured.

In the dry process of manufacture, the raw materials are dried before being ground and mixed for burning, while in the wet process they are mixed with water to be prepared for burning. The development of the long rotary kiln has made the use of the wet process economical and, since about 1915, most of the new plants have installed the wet process.

Dry Process.—The hard materials coming from the quarry must be crushed so that all pieces will pass a 2- or 3-in. screen. Large gyratory crushers are generally used. The materials are then dried in large hollow steel cylinders 50 ft. in length and 5 ft. in diameter. Waste gases are frequently used.

For proper burning about 85 per cent of the raw mixture should pass a 200-mesh sieve. Two stages of grinding are necessary, and are known as preliminary and final grinding. Preliminary grinding is generally done in a ball mill, known as a preliminator. The grinding is accomplished by the action of 6 to 8 tons of steel balls, 2½ to 5 in. in diameter, as the cylindrical

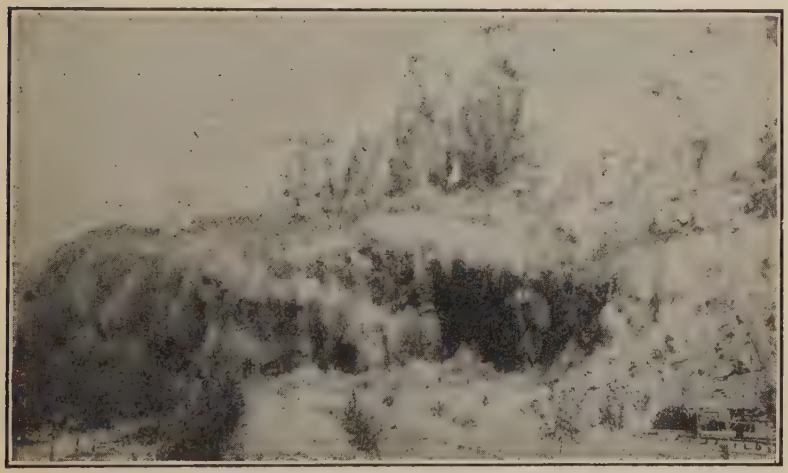


FIG. 14.—View of blast in stone quarry. Many tons of dynamite are used each year by the cement manufacturers in securing their supply of limestone.

steel drum revolves (see Fig. 21). The drum is 8 ft. in diameter and 5½ ft. in length. After preliminary grinding the materials should pass a 20-mesh sieve.

At this point the argillaceous and calcareous materials are combined, proportions of each material being based on chemical analyses. Final grinding is usually done in a tube mill which is 22 ft. in length and 5 or 6 ft. in diameter. The charge in a tube mill is about 15 tons of flint stone or steel balls. The material as it leaves the tube mill is ready for burning with about 85 per cent passing a 200-mesh sieve.

Wet Process.—Prior to 1915, marl and clay were the only raw materials used in the wet process. Since then more and

FIG. 15.—Preliminary crushing of stone is accomplished in a giant gyratory crusher.

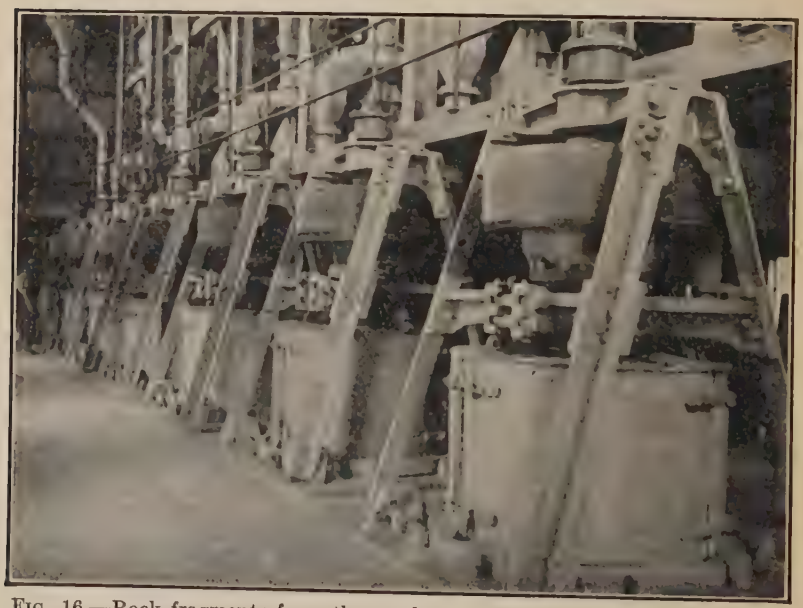


FIG. 16.—Rock fragments from the crusher are pulverized in mills of various types. This is a battery of centrifugal mills used for preliminary grinding.

more plants have been installing the wet process for use with limestone and shale as the raw materials. Manufacturers are not unanimous in the feeling that the wet process is better than the dry and those believing in the latter have been developing special blending bins for the purpose of securing more uniform raw mixtures.

The limestone and shale are first reduced in size so as to pass through a 20-mesh sieve, without being dried. The materials are then mixed with water into a slurry and ground so that

FIG. 17.—Long, horizontal rotary kilns in which the raw materials are burned into clinker.

85 per cent will pass through a 200-mesh sieve. Until about 1925 the slurry was introduced directly into the kiln, but since that date several manufacturers have been removing the water before introducing the raw mixture into the kiln. The removal of the water is accomplished by special driers using waste heat from the kiln.

Heating Raw Materials to Incipient Fusion.—Present-day practice is to burn the raw mixture in a long horizontal rotary kiln, which may be 150 to 343 ft. in length and 5 to 12 ft. in diameter. The average kiln is about 200 ft. long and 10 ft. in

diameter. It consists of a steel drum supported on rollers at intervals and is lined with fire brick. The speed of rotation is about three-fourths of a revolution per minute and the inclination with the horizontal is ½ to ¾ in. per foot. Fuel is introduced at the lower end while the raw materials are entering at the upper end. The smoke and gases pass out the upper end which is connected to a chimney.

The fuel ordinarily used is coal pulverized so that 95 per cent will pass a 100-mesh sieve. It is blown into the kiln by means of an air blast. Gas and oil are also used as fuels.

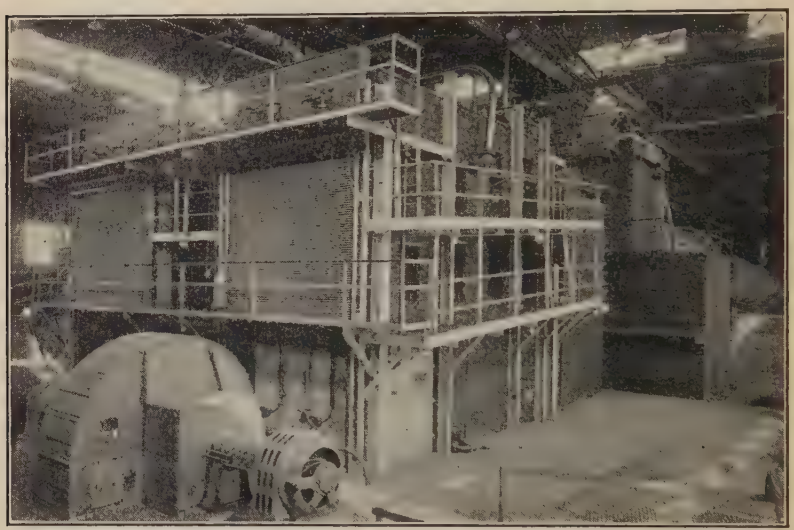


FIG. 18.—One of the developments in cement manufacturing methods has been the conservation of the heat produced in burning. This view shows waste heat room at the upper end of the kiln.

The raw materials gradually work themselves down through the long kiln in about an hour. They are heated to a temperature of 1400 to 1500°C. at which temperature clinker of a black or a greenish black color is formed. It has a vitreous luster and is quite hard. The output of a rotary kiln varies from 500 to 3,000 bbl. per day, depending upon its size. In producing a 376-lb. barrel of cement about 175 lb. of coal are burned and 600 to 700 lb. of raw materials are used.

The introduction of the rotary kiln about 1900 was probably the most important development in the manufacture of cement and has made it possible to put cement on the market at a price

sufficiently low to permit of its general use. At first the vertical kiln was used. Alternate layers of the raw materials and coke or wood were put into place and fired. In order to remove the clinkers and recharge the kiln it was necessary to cool the kiln. The capacity of such a kiln was only about 100 bbl. per day.

Grinding the Clinker.—Conservation of heat is an important item in the reduction of operating costs. The clinker is heated in the kiln to a temperature of 2500 to 3000°F. and much of this heat can be recovered as the clinker is cooled. Formerly, and in some cases still, the clinker was permitted to cool in air with a 100 per cent loss of this heat. Special cooling apparatus

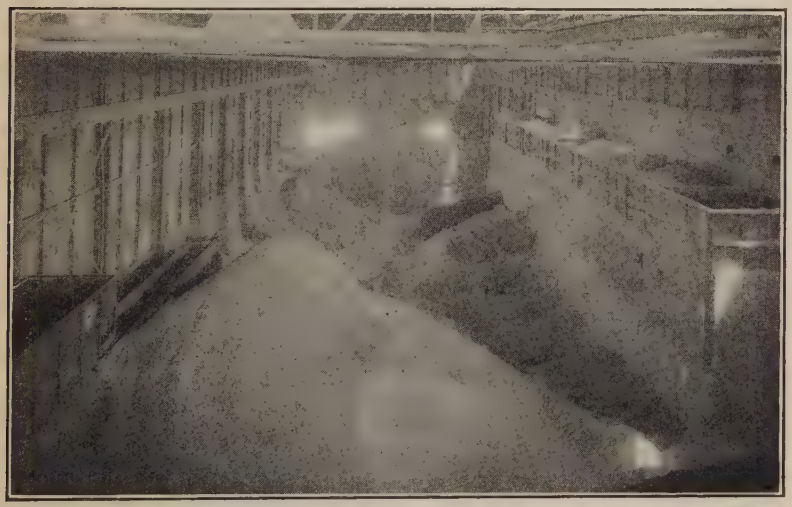


FIG. 19.—Clinker in storage waiting to be ground.

has been developed which recovers much of the heat. The recovered heat is returned to the furnace to be used in burning more clinker.

In order that the cement may not set too rapidly when used in mortar or concrete, a material is added to retard the set. The sulfates of calcium which are known as gypsum ($CaSO_4 + 2H_2O$) and plaster of Paris ($CaSO_4 + \frac{1}{2}H_2O$) are used. The usual amount is 2 per cent. Retarder may be added to the clinker before it is ground or after the clinker has had a preliminary grinding.

The clinker is ground in the same manner as the raw materials. The final product, however, must be so fine that at least 78 per

cent will pass through a 200-mesh sieve. The clear opening between wires is 0.0029 in., and there are 40,000 openings per square inch.

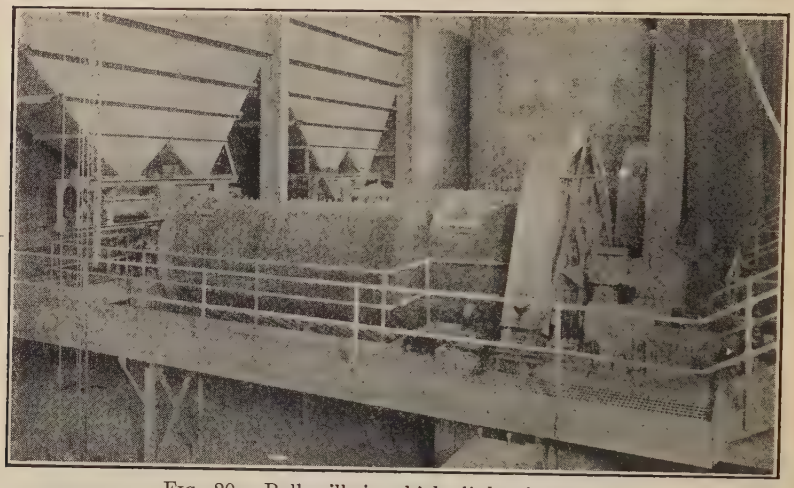


FIG. 20.—Ball mills in which clinker is ground.

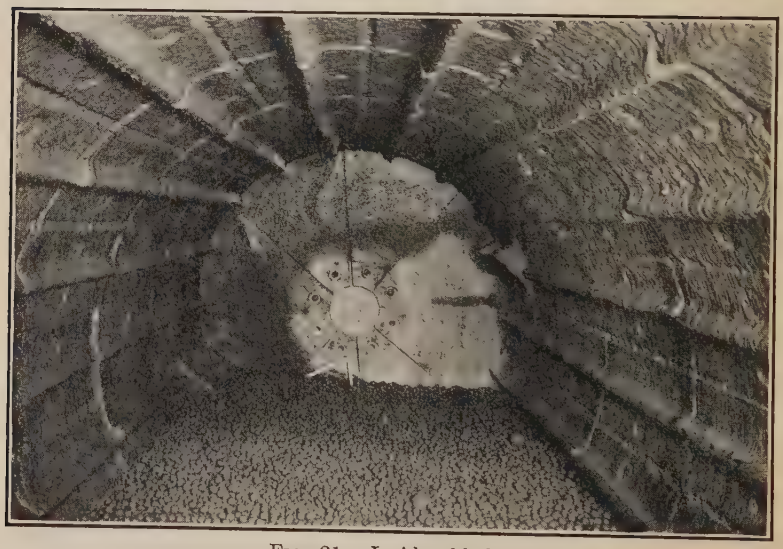


FIG. 21.—Inside of ball mill.

Ageing.—Following the final grinding it is advisable to allow the cement to aerate for 10 days to 2 weeks. During the late summer months when the demand is the heaviest, the cement

is frequently bagged immediately and shipped. Ordinarily a week may elapse between the grinding and its use in concrete.

The purpose of ageing is to permit any free lime present in the cement to hydrate before it is used in concrete. Occasionally during the burning of the clinker some free lime becomes encased in the center of the clinker and is not changed into clinker. Grinding liberates the free lime. Free lime expands many times its original volume as it absorbs moisture. It is highly desirable that the free lime do its expanding before it is incorporated in concrete. The percentage of unsound cement is quite small.

Bagging.—Practically all cement shipped prior to 1927 was in cloth bags, containing 94 lb. net. The original unit of measure was the barrel containing 376 lb. net. The first cements brought into this country and the first cements made in this country were shipped in wooden barrels. Occasionally now cement is shipped in bulk in gondola or box cars.

Multiple wall-paper bags made similar to the cloth bags came into extensive use in the year 1927 and give promise of replacing to a large extent the cloth bag. The paper bags are made with five thicknesses of paper and are claimed to be moisture proof. Because of the smoother surface of the paper not so much cement remains in the paper bag as in the cloth bag, when the bags are emptied. Cement sold in paper bags costs a little more than the net price of that sold in cloth bags. Some contractors, however, consider it cheaper in the long run to use the paper bags.

The barrel is the common unit of measure in designating quantities of cement even though the size of the package is one bag. There has been some agitation to change the size of the bag, as 94 lb. is a little heavy for the average workman to handle except for short periods of time. Many people have become accustomed to the size now in use, so that it would cause considerable confusion to change to any other size.

A small charge, usually 10 cts. per bag, is made by the manufacturer to the dealer when the cement is shipped. The dealer likewise charges his customers 10 cts. per bag. The money is refunded when the bags are returned. The charge does not cover the cost of the bag but is made in an effort to have all the bags returned. The dealers are required to clean the bags and tie

FIG. 22.—Sacking the cement. The bags are filled by machines that force the cement through a self-closing valve in the bottom, after the sack has been tied at the top.

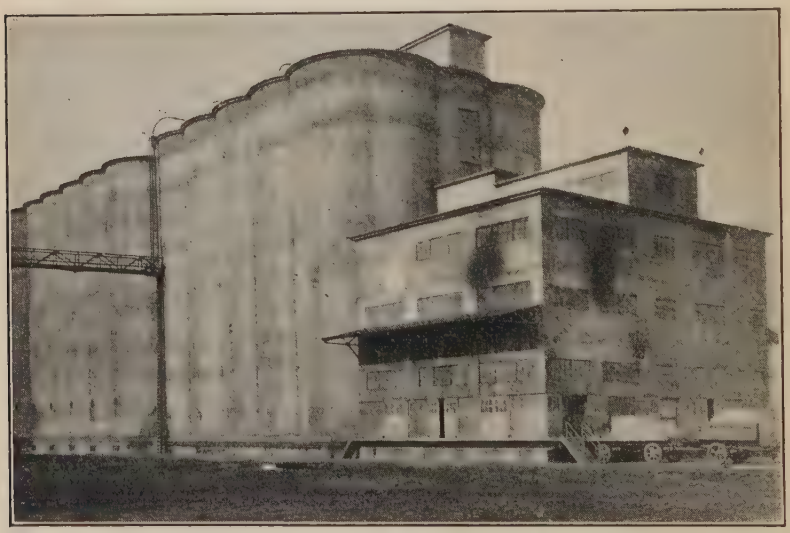


FIG. 23.—Cement storage bins at factory. In the slack selling periods stocks of cement are built up to meet the heavier demands of other seasons.

them up in bundles of 50. About 1 lb. of cement is cleaned from each bag.

The first step in bagging is to wire shut the top of the bag. A special device is inserted into the bottom of the bag for filling. The bag is slipped then over a nozzle and the cement is blown in. When 94 lb. are in the bag an automatic cut off stops the flow of cement and the bag drops on a belt to be conveyed to the loading platform.

Chemical Composition.—Properly prepared portland cements will have the following chemical composition:

Lime (CaO)	60 to 64 per cent
Silica (SiO_2)	19 to 25 per cent
Alumina (Al_2O_3)	5 to 9 per cent
Magnesia	5 per cent maximum
Sulfuric anhydride (SO_3)	2 per cent maximum
Iron oxide	0 to 4 per cent

The magnesia and sulfuric anhydride are limited to the above percentage by the standard specifications.

Specifications.—The specifications under which portland cement is produced in the United States are those adopted by the American Society for Testing Materials. At the time of the formation of this society in 1898 cement was being manufactured to meet a large number of specifications. Engineers differed in their ideas and manufacturers found it difficult to meet these various specifications. This led to a demand for standardization. When the new standard appeared, it was quite generally accepted.

With the adoption of the standard specifications the manufacturers began to develop quantity production and have spent most of their efforts along this line. Now there is a tendency to produce special cements for various purposes, such as, high early strength, waterproofing, and color effects.

Standard Specifications for Portland Cement of the A. S. T. M.

Serial Designation C9-26

1. *Definition.*—Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous mate-

rials with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

I. Chemical Properties

2. The following limits shall not be exceeded:

	Per Cent
Loss on ignition	4.00
Insoluble residue	0.85
Sulfuric anhydride (SO_3)	2.00
Magnesia (MgO)	5.00

II. Physical Properties

3. *Fineness.*—The residue on a standard No. 200 sieve shall not exceed 22 per cent by weight.

4. *Soundness.*—A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

5. *Time of Setting.*—The cement shall not develop initial set in less than 45 min. when the Vicat needle is used or 60 min. when the Gillmore needle is used. Final set shall be attained within 10 hours.

6. *Tensile Strength.*—The average tensile strength in pounds per square inch of not less than three standard mortar briquets, composed of 1 part of cement and 3 parts of standard sand, by weight, shall be equal to or higher than the following:

Age at test, days	Storage of briquets	Tensile strength, pounds per square inch
7	1 day in moist air, 6 days in water	225
28	1 day in moist air, 27 days in water	325

7. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

III. Packing, Marking, and Storage

8. *Packages and Marking.*—The cement shall be delivered in packages as specified, with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. When shipped in bulk, this information shall be contained in the shipping advices accompanying the shipment. A bag shall contain 94 lb. net. A barrel shall contain 376 lb. net. All packages shall be in good condition at the time of inspection.

9. *Storage.*—The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

IV. Inspection

10. Every facility shall be provided the purchaser for careful sampling and inspection either at the mill or at the site of the work, as may be specified by the purchaser. At least 12 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 33 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test need not be made if waived by the purchaser.

V. Rejection

11. The cement may be rejected if it fails to meet any of the requirement of these specifications.

12. Cement remaining in storage prior to shipment for a period greater than 6 months after test shall be retested and shall be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement if, upon retest after drying at 100°C. for 1 hour, it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within 28 days thereafter. The provisional acceptance of the cement at the mill shall not deprive the purchaser of the right of rejection on a retest of soundness and time of setting at the time of delivery of cement to the purchaser.

15. Packages varying more than 5 per cent from the specified weight may be rejected, and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

Compressive Strength[1]

The following specification was proposed in 1916 as a tentative standard with the idea that it might at some time be added to the standard specifications for cement. This has never been done.

The average compressive strength in pounds per square inch of not less than three standard mortar test pieces composed of 1 part cement

[1] A. S. T. M. serial designation C9-16T.

and 3 parts standard sand, by weight, shall be equal to or higher than the following:

Age at test, days	Storage of test pieces	Compressive strength, pounds per square inch
7	1 day in moist air, 6 days in water	1,200
28	1 day in moist air, 27 days in water	2,000

The average compressive strength of standard mortar at 28 days shall be higher than the strength at 7 days.

NOTE.—The specifications prior to 1926 contained a provision that the specific gravity should not be less than 3.10 for the gray portlands and 3.07 for the white portlands.

VALUE OF TESTS

Soundness.—The purpose of the soundness test is to determine if there is anything present in the cement which would cause disintegration of the concrete in which the cement would be used. In the manufacturing process occasionally free lime is produced. As it absorbs moisture, free lime expands many times its original volume, which would cause disintegration of the concrete in which it mignt be used. Proper ageing of the cement will eliminate any free lime. The specifications, therefore, permit a retest at any time during the first 28 days.

In this test a pat of cement paste is molded on a glass plate. The pat is made 3 in. in diameter and ½ in. in thickness at the middle and tapering out to a thin edge. The pat is placed in a moist closet as soon as it is molded. After 24 hours it is placed in a steam bath for 5 hours, at the end of which time it is examined for evidences of unsoundness.

Time of Setting.—The rate of setting is an important item in the handling and finishing of concrete. During the setting period the concrete loses its ability to be made into different shapes and becomes a hard, immovable mass. After the concrete has become sufficiently hard to hold its shape, the hardening period, as it is called, begins. As a concrete hardens it gains in strength.

Sufficient time must elapse between the mixing and setting to permit the concrete to be placed. After the concrete is once in place it is desirable that the setting and hardening action take place. The requirements for various jobs will be different

and sufficient latitude is given to include almost all construction work. It is necessary that any one using cement plan his work so that the concrete may be gotten into place before the setting action takes place.

Two stages of setting are defined in the specifications. They are known as initial set and final set. Initial set occurs when the cement paste will support the ¼-lb. Gillmore needle without appreciable indentation, or when the Vicat needle ceases to penetrate past a point 5 mm. above the bottom of the cement paste which is molded in the vulcanite ring. Final set occurs when the paste will support the 1-lb. Gillmore needle or the Vicat needle, without appreciable indentation.

Fineness of Grinding.[1]—In general the strength of concrete is increased with greater fineness of grinding for each particular brand of cement. It is not necessarily true that a brand of cement which is ground finer than another will have a greater strength. The principal result of finer grinding is to hasten the early hardening of the concrete. Those particles of cement which are ground fine enough to pass through the 200-mesh sieve are the ones which react with the water and give strength to the mass. As the proportion of material which will pass the 200-mesh sieve is increased, there is more material which will give strength. Fine grinding of cement is more effective in increasing the strength of lean mixtures than rich ones, and in producing higher early strengths.

Tension Tests.—The cement to be of any value as a binding material must have the ability to develop strength. To check on this item a tension test has been devised in which the cement is mixed with standard Ottawa sand. The resulting mortar is molded into briquets which have a cross-sectional area of 1 sq. in. at mid-section. The briquets are tested at 7 and 28 days and it is prescribed that the minimum strength at 7 days shall be 225 lb. and at 28 days 325 lb. The question is frequently raised as to the value of a tension test when the concrete rarely ever is considered as having any tensile strength. On the other hand, satisfactory cements have been secured with the present specification.

Compression Tests.—It has been argued that the compression test is a better measure of the strength quality of the cement

[1] "Effect of Fineness of Concrete," *Structural Materials Research Laboratory Bull.* 4.

than is the tension test. The American Society for Testing Materials has prepared a tentative standard for the compression test. The procedure is similar to that of the tension test, except that the 2 by 4-in. cylinder is used as the test specimen instead of the briquet.

Questions

1. Describe the manufacture of portland cement. Distinguish between dry and wet processes of manufacture.
2. What is the purpose of adding gypsum or plaster of Paris to the clinker?
3. What is the purpose of ageing the cement?
4. What is the weight of cement per bag? per barrel? What is the usual assumption as to volume?
5. What is the chemical composition of cement?
6. Give physical test requirements of the A. S. T. M. for portland cement.
7. How is the time of setting controlled?
8. What is the effect of additional fineness of grinding?
9. Distinguish between setting and hardening.

CHAPTER 3

SPECIAL CEMENTS

In addition to the standard grade of portland cement discussed in the previous chapter, there are cements which develop higher earlier strengths and others which are specially prepared for waterproofing purposes. The high early strength cements may be divided into two groups, aluminate and high early strength portlands. For a discussion of high early strength concrete, see Chap. 11.

Aluminate Cement

Aluminate cements are made in practically the same manner as is portland cement, but with different raw materials. The most common combination for portland cement is limestone and shale. In aluminate cements the shale is replaced by an aluminum ore called bauxite. Bauxite is an aluminum compound represented by the chemical formula $Al_2O(OH)_4$, but is generally impure and may contain water, iron oxide, silica or tannic acid. Bauxite is found in the United States in Arkansas, Georgia and Tennessee. Most of the imported bauxite comes from the Guianas, Dalmatia, and France.

Aluminate cement concrete at the end of 24 hours after placing has greater strength than similar concrete made with standard portland cement at the end of 28 days. It can also be used successfully at lower air temperatures than can portland cement concrete. On the other hand the cost is from three to four times as much as that of portland cement and more care must be exercised in the production of the concrete and during the first 24 hours of curing.

Studies of aluminate cements began in the early part of this century in France, Germany, and the United States. The first work in this country was done by H. S. Spackman in conjunction with E. W. Lazell. Later the work was continued with E. L. Conwell. P. H. Bates also made some studies.

At the same time the French and Germans were investigating this new cement. The French were the first to produce it on a commercial basis, under a patent issued in 1908. Their product is known as "Cement Fondu." It was first used in a railway tunnel.

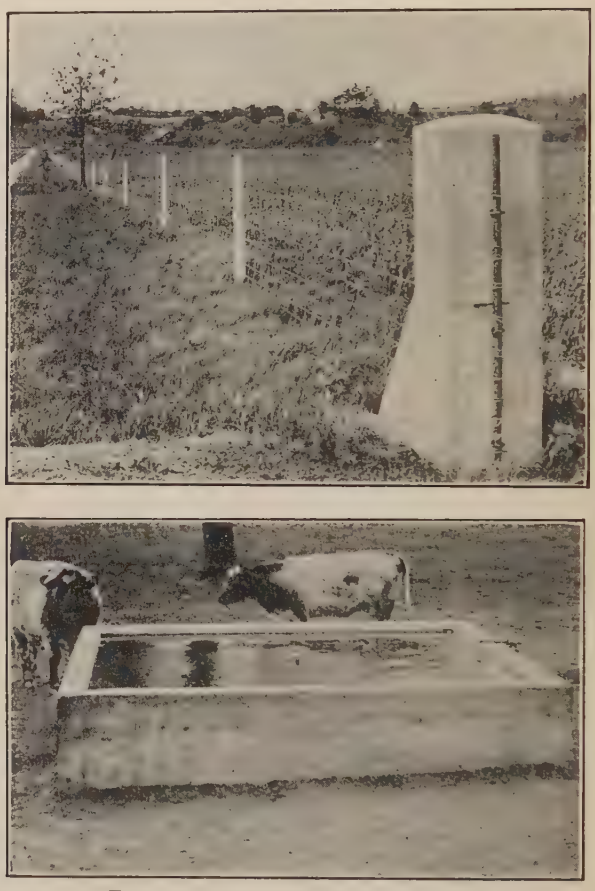


FIG. 24.—Some farm uses of concrete.

During the World War the military forces constructed bases for the heavy artillery with aluminate cement concrete. Its showing during the war aroused the attention of engineers generally and since then production has started in several countries. Manufacture began in Germany in 1924. Several plants were started in England in 1923. The first American-

made aluminate cement was offered for sale in the United States in June, 1924. It is known as Lumnite and is the only American brand. It is produced by The Atlas Lumnite Cement Company.

Chemical Analyses.—Chemical analyses of Lumnite cement indicate approximately the following composition:

	Per Cent
Silica	3 to 8
Iron oxide	14 to 18
Alumina	37 to 39
Lime	31 to 41
Magnesia	¾ to 1
Sulphur anhydride	½ to 1½

Physical Properties.—The chief physical property of aluminate cement is its ability to gain strength rapidly. Concrete made

FIG. 25.—View of a reinforced-concrete stadium.

with aluminate cement has greater strength at the end of 24 hours than has similar concrete made with portland cement at the end of 28 days. Another special characteristic is its ability to gain strength at lower temperatures than portland cement.

Aluminate cements may be subjected to the same tests as portland cement. The results in some of the tests are similar to those of portland cements while in others they are different.

Normal Consistency.—Normal consistency occurs within the same range of percentages of water as for portland cement.

Specific Gravity.—The specific gravity is also about the same as for portland cement.

Fineness of Grinding.—Aluminate cement is generally ground much finer than is the average portland cement, only about 5

per cent being retained on the 200-mesh sieve as compared to about 15 per cent for the average portland cement. The standard specifications for portland cement permit a maximum of 22 per cent to be retained on the 200-mesh sieve.

Soundness.—Aluminate cement will pass the soundness test for portland cement.

Time of Setting.—In the time of setting test there is not much of an interval between initial set and final set. Initial set is slower than for the average portland cement and final set is about the same. Aluminate cement concrete remains soft and workable longer than portland cement concrete. Once the stiffening action starts, aluminate cement concrete becomes hard very rapidly. Concrete finishers accustomed to portland cement will find it difficult at first to do their work at the proper time.

Tension and Compression Tests.—Aluminate cement will easily pass the A. S. T. M. tension and compression test requirements for portland cement. The strengths at the end of 1 day are greater than those required at either 7 or 28 days.

Flash Set.—All advertisements of Lumnite cement advise not to mix portland cement with the Lumnite. Tests were made at the University of Michigan to determine the effect of various combinations on the time of setting. The general conclusion was that when the mixture of cements contained between 33 and 90 per cent portland cement, there would be a flash set. In some cases the cement set so rapidly that it was not possible to make a determination before the set had taken place.

Effect of Temperature.—One of the claims for Lumnite cement is that low temperatures during the curing period do not affect the compressive strength nearly as much as they do portland cements. Some tests were made at Michigan State College to determine this effect with Lumnite cement.

The principal result noted was that the concrete did not gain strength while frozen nor during the thawing period. A set of cylinders was placed, immediately after molding, in a temperature below freezing. After 24 hours the cylinders were placed in water at 50°F. for 3 hours to remove the frost. Upon removal of the forms the cylinders fell to pieces in handling.

The concrete may not be permanently affected by freezing. The concrete which was given 28 days to harden following the freezing has practically the same strength as the concrete handled in the regular manner at 1 day. The ability to gain strength

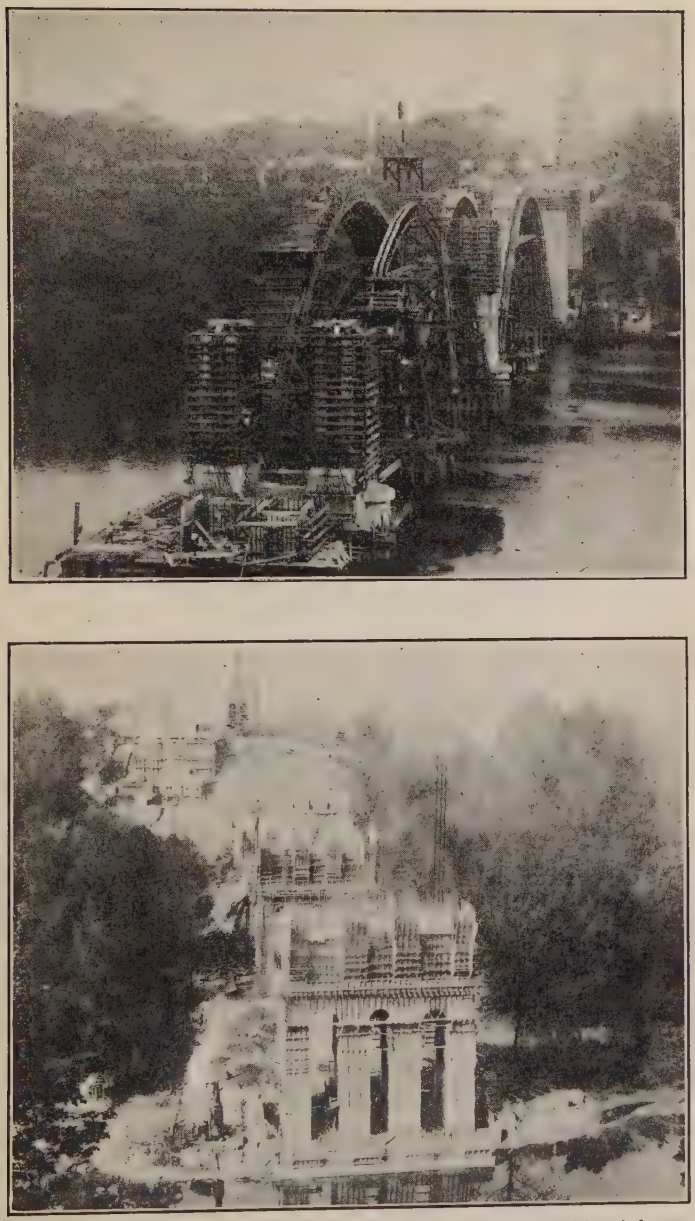


FIG. 26.—Views showing construction work on several bridge jobs.

quickly, however, is somewhat impaired. At the end of 3 days after thawing, the Lumnite cement concrete was stronger than similar portland cement concrete at 28 days but cured in the normal way.

High Early Strength Portland Cements

The production of high early strength portland cements is a comparatively recent development, the first American-made

Fig. 27.—An air hammer is often used to remove old concrete.

cement being offered for sale in 1927. Most maunfacturers are producing standard brands which exceed by a wide margin the minimum strength requirements of the A. S. T. M. Under favorable conditions these cements will produce concrete which will develop strengths higher than is normally expected of portland cement concrete. A number of manufacturers are advertizing that high early strength concrete can be made with their cements and creating the impression that such is not the case with other brands, whereas any standard brand of portland cement can be made to produce higher strengths in concrete by the methods outlined in Chap. 11. Not all cements, therefore, which produce high early strength concrete may be classed as high early strength cement.

Only one manufacturer has revealed the process by which his high early strength cement is produced. The same raw materials are used in its manufacture as in that of the standard portland cement, but the lime content is increased slightly. Burning is accomplished in two stages. Following the preliminary burning, the clinker is given a grinding and then a second burning. The clinker is finally ground, in two stages, so that over 90 per cent will pass the 200-mesh sieve.

One manufacturer is producing cement under a foreign patent while another has developed a process which is being patented, but neither cares to divulge information as to the method of manufacturing.

Concrete made from these cements does gain strength more rapidly than similar concrete made with the standard brands. The strengths at later ages are not, however, correspondingly greater as in the case of the early ages. These cements are of too recent origin to know fully their possibilities and limitations.

The cost of the high early strength portland cements is somewhat greater than that of the standard brands, varying from $1 to $1.25 per barrel more. Because of the possibility of securing use of the concrete at a comparatively early date, the public seems to be willing to pay this amount extra for the cement.

Waterproof Cements

Certain cements are available for which the manufacturers claim special waterproofing qualities. These generally are standard brands with the waterproofing material incorporated during the grinding of the clinker.

Much of the waterproofing cement sold in the United States is manufactured under what are known as the "super" cement patents. Any manufacturer may produce a "super" cement upon securing the privilege from the owner of the patent. A special grade of tannin known as Gallo tannin, which is produced from oak gall nuts, is added at the same time as the retarder.

The addition of the waterproofing material may reduce somewhat the strength producing properties of the cement. The desired concrete strengths may be secured, however, by using the proper amount of cement. Anyone using waterproof cement for waterproofing purposes should exercise just as much care in the production of the concrete as in any other case.

Waterproofing cements sell for about 75 cts. to $1 more than the regular cements.

White Portland Cement

The grey color of portland cement is caused largely by the presence of iron oxide in the limestone and shale. Except for the impurities which exist in the raw materials all portland cement would be colorless or white. Iron oxide occurs in the finished grey cement in quantity up to 4 per cent, but is not an essential constituent.

Pure calcite limestone and white clay, from which two of the cement companies produce white cement, are found in Pennsylvania. This cement in combination with white aggregates produces white concrete and stucco. The chemical composition of the grey and white cement is essentially the same except that the iron oxide content of white cement is usually $\frac{1}{2}$ of 1 per cent or less. The physical properties are much the same, except that the white cement is ground finer than the average grey cement. Five to ten per cent retained on the 200-mesh sieve are average values for the white cement and 15 to 20 per cent for the grey cements. The specific gravity is less, being 3.05 for the white cement. Specific gravity is no measure of quality, however.

Uses.—White cement is used principally (1) in stucco for external plastering of buildings; (2) for setting of fine building stone to avoid staining; (3) in the manufacture of ornamental concrete units; (4) for facing concrete blocks; and (5) in the manufacture of tile, mosaics, etc.

Questions

1. What is the difference between aluminate and portland cements?
2. What are the advantages and disadvantages of aluminate as compared with portland cement?
3. What happens when the two cements are mixed?
4. What is meant by high early strength portland cement?
5. What is water-proof cement?
6. How does white cement differ from gray cement? For what purposes is white cement used?

CHAPTER 4

MINERAL AGGREGATES

Mineral aggregates as used in portland cement concrete are usually particles of rock, either naturally or artificially produced, blast furnace slag or cinders. In recent years a light-weight aggregate known as Haydite has been brought on the market for use principally in making building units and structural concrete.

Fine and Coarse Aggregate.—Aggregates are arbitrarily divided into two sizes. The combination of particles smaller than ¼ in. is known as *fine aggregate* and the combination of those larger than ¼ in. as *coarse aggregate*. Fine aggregate is usually sand which is naturally disintegrated particles of rock. Coarse aggregate may be either pebbles or crushed rock or stone. Pebbles are the naturally formed particles and are sometimes known as gravel. The former designation is better because it has only one meaning, since gravel is sometimes used to designate a combination of both sand and pebbles. Slag, cinders, and Haydite may be separated into both fine and coarse aggregate sizes.

Production

Sand and Pebbles.—At many places throughout the United States and Canada there are deposits of sand and pebbles. Gravel pits, as they are called, are quite frequent in the northern half of the United States which has been covered at various times by glaciers. The theory is that the glaciers pushed large masses of rock ahead of them as they moved south. As the rock was pushed along it was broken up into smaller pieces and had the corners rounded off. Sand deposits are frequently found in and along streams and rivers. The proportions of sand and pebbles in a pit will vary considerably in the pit and from one pit to another. Some pits are nearly all sand while others contain very little.

Production consists in stripping off the overburden, excavating the material, and hauling it to a plant to be screened and washed. Practically all deposits are covered with earth which may be

FIG. 28.—Views in (top) stone quarry and (bottom) gravel pit. A drag line is being used to remove the gravel.

removed by any of the ordinary methods of excavation, such as steam, gas or electric shovels, drag line, or sluicing. The excavation of the material is accomplished by means of power

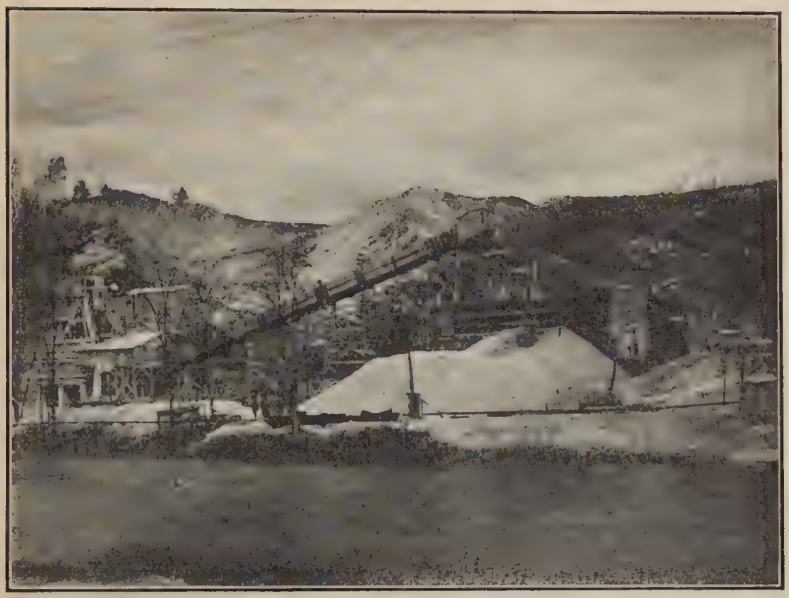


FIG. 29.—General view of sand and crushed-stone plant. Materials are taken from hill in background which contains approximately 25 per cent sand and 75 per cent stone.

FIG. 30.—A close-up view of plant shown in Fig. 29. The pit is on the opposite side of the plant from the river.

shovels or the drag line. When the deposits are under water it is not uncommon to use a suction pump to move the material to some point where it may be separated from the water.

In most pits are found pieces of rock too large to be used without crushing. Crushing machinery is generally installed for the purpose of reducing these boulders to such sizes that they may be incorporated with the pebbles.

At the plant the materials are elevated so that during the washing, screening, and loading, they are moving by gravity. The material is separated into various sizes on rotary screens or horizontal vibrating screens. During the screening, water is played on the materials so that by the time the screening oper-

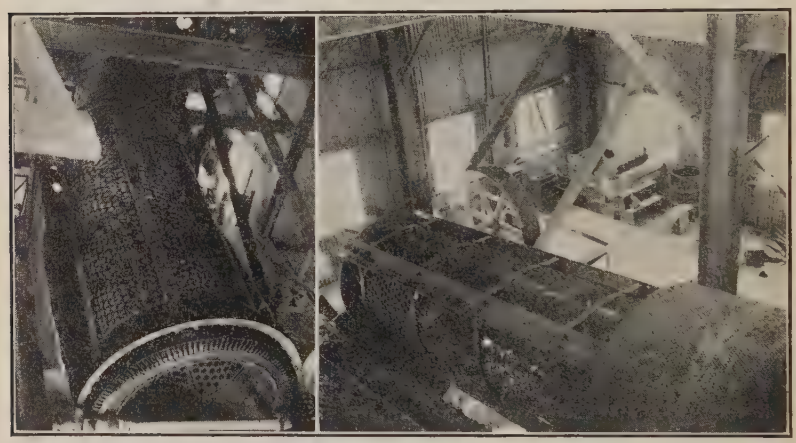


FIG. 31.—*Left*, Scalping screens used to remove larger and smaller pieces which are not of the proper size. *Right*, Sizing screens used to separate the aggregate into different sizes.

ation is complete they are practically clean. The various sizes are then recombined as the purchaser requires. In many cases, however, the requirements of the engineers are such that not all of the output can be used and some must be wasted. In many of the pits there is a surplus of sand. The proportions for concrete are such that 1 part of sand is used for each $1\frac{1}{2}$ or 2 parts of coarse aggregate. Unless there are other materials available in the territory as coarse aggregate, the sand must be wasted or other uses found for it.

Crushed Stone.—Crushed stone is prepared from solid rock. The words "stone" and "rock" are used more or less inter-

changeably, but the former more truly applies to pieces of the latter. The word rock refers to the large natural masses.

There are three general classifications of rock, igneous, sedimentary, and metamorphic. *Igneous rocks* are those formed

Fig. 32.—Top, battery of vibrating screens. Bottom, "live roll" grizzlies.

by the action of heat. They are generally hard and tough, granular, and have practically no bedding planes. Granite and basalt are examples. *Sedimentary rocks* are those formed by the consolidation of sediment deposited from water. Bedding planes are apparent. Limestone and sandstone are examples. *Meta-*

morphic rocks are either igneous or sedimentary rocks which have been changed in structure and character by the action of heat, pressure, and movement. Marble is a metamorphic limestone and gneiss a metamorphic granite. *Trap rock* is the name which has been applied to any dark-colored, fine-grained igneous rock.

Granite, trap rock, and limestones are the most common rocks from which crushed stone is prepared for use in concrete. Some limestones are too soft, and only occasionally is a sandstone found which is sufficiently hard. Traps and granites are excellent materials.

FIG. 33.—View of crushing and screening plant of company producing crushed stone. Cars are loaded on the tracks underneath the storage bins.

Preparation of crushed stone for use is not as easy as that of pebbles. Overburden must be removed, holes drilled for charges of dynamite, the dynamite placed and set off, the broken rock loaded into cars and taken to a plant for crushing and screening. Air hammers are most generally used for drilling the holes and power shovels for loading the large pieces into railroad cars. Crushing is usually accomplished in two stages known as *primary* and *secondary* crushing. Gyratory and jaw crushers are the types most commonly used for both operations. Between the two crushings the material of proper size is removed by a screening operation.

The operations of screening are quite similar to those described for sand and pebbles. Not many plants, however, wash the crushed stone. Usually some dust is produced in the crushing and screening operations. The dust is objectionable when the stone is to be used in portland cement concrete and in some

FIG. 34.—*Top*, airplane view of pit system at blast-furnace plant. *Lower left*, showing strata in slag pit. *Lower right*, 18-year-old slag concrete being removed.

instances engineers have insisted that the stone be washed in order to remove this dust. Producers will install washing equipment only as the purchaser demands it. The various sizes are combined as the material is run into the cars for shipment.

Blast-furnace Slag.—Blast-furnace slag is the non-metallic product consisting essentially of silicates and alumino-silicates of

lime which is developed simultaneously with iron in a blast furnace.[1] Blast-furnace slag is produced in the kiln at the same time as the pig iron. In the furnace the slag rises to the surface of the molten mass and is drawn off at a higher level than the iron. The slag is placed in pits to cool. As drawn from the furnace it has a temperature of 3500°F. Granulated slag is produced by quickly cooling the molten slag with water. Air-cooled slag must be removed from the pit with a power shovel and taken to crushers to be reduced to the desired sizes as in a crushed stone plant.

Chemical analysis limits for average blast furnace slags are given in the following table:

	Per Cent
Silica	32 to 48
Lime	17 to 45
Alumina	8 to 20
Magnesia	1 to 12
Iron	1 to 3
Sulphur compounds	0.5 to 2.5

The weight per cubic foot is usually at least 70 lb. for screened material between the 1½-in. screen and the No. 4 sieve. The percentage of voids varies from 38 to 46. Specific gravity is about 2.3.

Blast-furnace slag has been used as a concrete aggregate for many years in pavements, bridges, and buildings. Its use has been limited, of course, to the iron and steel manufacturing districts. The use of blast-furnace slag is increasing in the United States.[2]

Cinders.—Cinders are produced as waste material from steam boilers using bituminous coal. They are hard, vitreous, granular, porous and light in weight. Cinders weigh about 45 lb. per cubic foot. They are used in buildings for floor and roof construction where there is no wetting and drying or freezing and thawing. They are commonly used in making a light-weight concrete building block. The cost is low since they are a waste material and may usually be had for the hauling.

[1] As defined by *American Concrete Institute Committee E-5 on Aggregates.*

[2] Bardsley, "Utilization of Blast-furnace Slag in Highway Improvement," a bulletin of the School of Mines and Metallurgy of the University of Missouri.

Haydite.—Haydite is a patented light-weight aggregate made from shales ordinarily used in the manufacture of brick.[1] The shale is ground to a maximum size of 1 in. It is then burned in a rotary kiln of the same type as used in the manufacture of portland cement. The shale is fed in at one end and comes out at the other end finished except for crushing and screening. The temperature in the kiln at the discharge end is approximately 2000°F. When the shale reaches the zone of this high temperature, it becomes viscous, incipient fusion takes place, the carbon content is oxidized and formed into gas. As the gas escapes from the shale, the latter is expanded into a light-weight cellular structure.

The product of the kilns is taken to a preparation plant where it is ground, screened and graded into the commercial sizes. The following sizes are available:

Designation	Range of sizes	Weight per cubic foot, loose	Use
A or No. 6	0 to 3/16 in.	56 lb.	Fine aggregate
B or 1/2 in.	3/16 to 1/2 in.	47 lb.	Coarse aggregate for precast concrete units
C or 3/4 in.	3/16 to 3/4 in.	44 lb.	Coarse aggregate for larger precast units and in reinforced concrete.

The specific gravity is approximately 2.52.

Haydite aggregate concrete will weigh from about 90 to 100 pounds per cubic foot as compared to 150 lbs. for sand and pebble or crushed stone aggregate. A typical chemical analysis is as follows:

	Per Cent
Silica	59.48
Iron oxide	8.48
Aluminum oxide	16.14
Magnesium oxide	2.15
Lime	8.64
Alkalies	4.42
Loss on ignition	0.69

[1] Manufactured by a number of companies in various parts of the United States and Canada under patents issued to S. H. Hayde of Kansas City, Missouri.

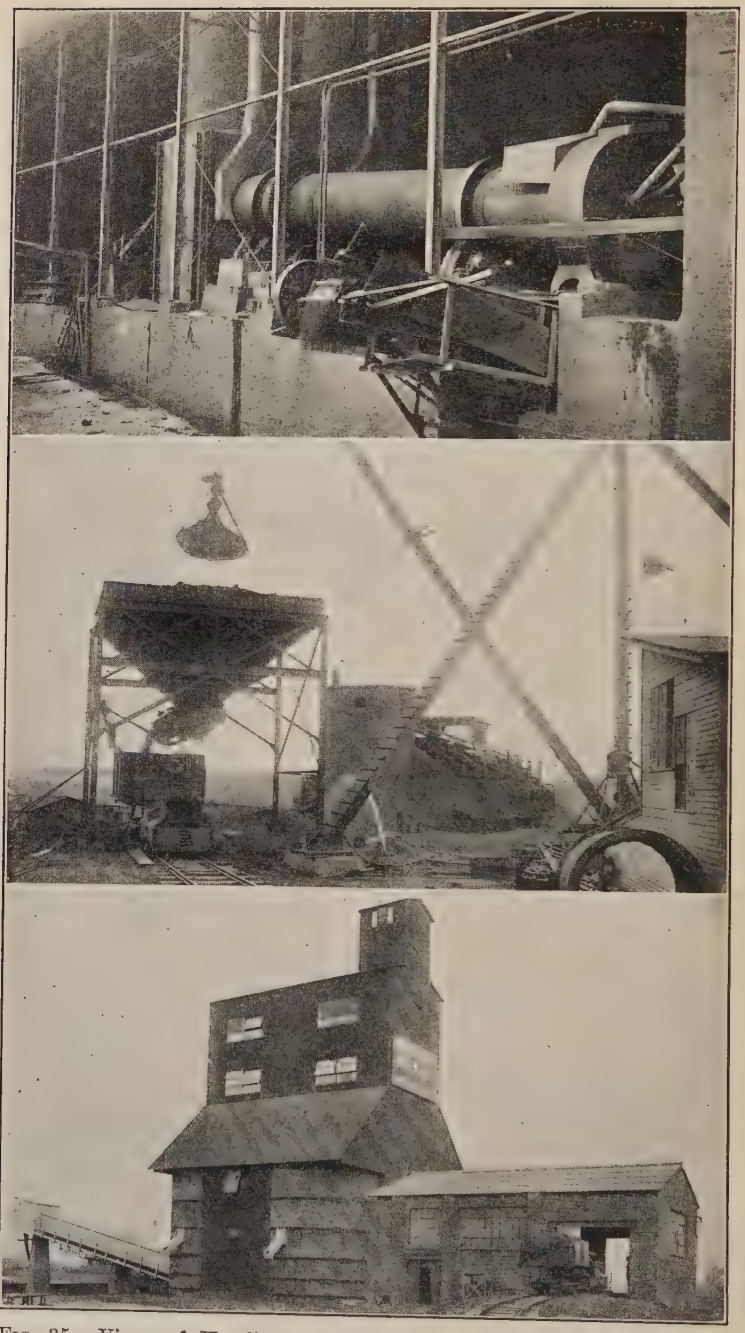


FIG. 35.—Views of Haydite manufacturing plant. *Top*, kiln and clinker conveyor. *Center*, handling from storage pile to loading chute. *Bottom*, grinding plant.

TABLE 3.—PHYSICAL PROPERTIES OF SOME FINE AGGREGATES[1]

Reference number	Origin	Description	Sieve analysis, percentages passing							Specific gravity	Weight, pounds per cubic foot	Voids	F.M.	Percentage absorption by weight
			100	48	28	14	8	4	⅜					
0	Ottawa, Ill.	Standard Ott. sand		0	1	100				2.65	105.4	0.363	2.99	0.05
1	Joliet, Ill.	Sand	34	75	100					2.76	107.0	0.380	0.91	0.16
2	Trap Rock, Pa.	Trap screenings	11	16	23	33	52	91	100	2.90	121.5	0.329	3.74	0.10
3	Algonquin, Ill.	Sand	5	19	46	67	84	100		2.71	116.6	0.309	2.79	0.36
4	Kansas City, Mo.	Kaw River sand	0	3	40	75	91	98	100	2.63	109.5	0.333	2.91	0.16
5	Chicago, Ill.	Lake sand	1	60	99	100				2.64	103.0	0.375	1.44	0.20
6	Milwaukee, Wis.	Limestone screenings	23	37	52	67	84	97	100	2.75	123.4	0.280	2.40	0.40
7	Joplin, Mo.	Chats	3	9	20	32	57	100		2.60	101.6	0.373	3.79	0.10
8	Ottawa, Ill.	Banding sand	43	99	100					2.65	106.1	0.358	0.58	0.00
9	Chicago, Ill.	Limestone screenings	3	3	3	3	6	100		2.77	96.9	0.440	4.82	0.16
10	Gary, Ind.	Dune sand	6	95	100					2.67	101.1	0.393	0.99	0.20
11	Chicago, Ill.	Slag	5	9	16	25	45	89	100	2.68	103.7	0.379	4.11	0.56
12	Berlin, Wis.	Crushed granite	15	21	28	39	61	96	100	2.61	114.1	0.300	3.40	0.20
13	Fremont, Neb.	Platte River gravel	3	19	42	57	71	88	98	2.63	121.0	0.263	3.23	0.10
14	Mapleton, Pa.	Glass sand	3	32	93	99	100			2.62	95.1	0.419	1.73	0.40
15	Lorain, Ohio	Crushed slag	9	15	24	34	55	93	100	2.59	91.3	0.435	3.70	0.44
16	Buffington, Ind.	Granulated slag	7	15	37	76	98	99	100	2.50	80.5	0.483	2.69	0.34
17	Atlantic City, N. J.	Sea sand	9	95	100					2.73	107.4	0.370	0.95	0.25
18	San Diego, Cal.	Sand	1	7	24	48	75	94	100	2.65	105.6	0.361	3.50	0.52
19	Janesville, Wis.	Sand	1	14	57	73	82	90	99	2.65	116.1	0.298	2.84	0.12
20	Elgin, Ill.	Washed sand	2	12	51	71	86	98	100	2.69	114.0	0.321	2.81	0.52
21	Medicine Hat, Can.	Sand	1	5	32	61	79	92	99	2.64	112.5	0.317	3.30	0.32
22	Elgin, Ill.	No. 20 Unwashed	1	7	37	57	72	95	100	2.69	116.0	0.309	3.30	0.36
23	Greenup, Ill.	Sand	6	48	99	100				2.63	101.5	0.382	1.47	0.65
24	Attica, Ind.	Sand	4	10	25	51	78	97	100	2.67	112.1	0.332	3.33	0.63

[1] Compiled from Tables 4 and 5, in TALBOT and RICHART, "The Strength of Concrete—Its Relation to the Cement, Aggregates and Water," *Eng. Expt. Sta. Univer. Ill. Bull.* 137, pp. 48–49.

Results of a series of tests on Haydite concrete are given in the following table:[1]

Mix	Strength in pounds per square inch			
	7 days	14 days	28 days	60 days
1:2:3	1,587	2,226	2,601	3,263
1:2:3½	1,521	1,903	2,263	2,740

It is reasonable to assume that concrete made with Haydite aggregate will be subject to the same laws as will concrete made with the usual sand and pebbles or crushed stone aggregate. Richer mixes and higher curing temperatures, for instance, will

TABLE 4.—SIEVE ANALYSES RESULTS OF SOME COARSE AGGREGATES

Sieve	Results in percentages passing								
	Pebbles						Crushed stone		
	1	2	3	4	5	6	7	8	9
2-in.						100			
1½-in.	100	98	96	100		80		100	
1-in.	93	89	60			50	100		
¾-in.	73	58	46	69	91		77	25	89
½-in.						5	19		
⅜-in.	29	17	10	32	35		8	6	31
¼-in.							2	3	
No. 4	6	4	6	5	17				9
No. 8					7				1
F. M.	6.84	7.37	7.38	6.94	6.40	7.89	7.19	7.69	6.68

Number 1 was used in the construction of building No. 10 of the Victor Talking Machine Company, at Camden, N. J. in 1924.
Number 2 was used in the Newark Bay bridge of the Central Railroad of New Jersey. Sampled at the scow.
Number 3 was the same as No. 2 but was sampled at the mixer.
Number 4 was used in the superstructure of the new Portland Cement Association building, in Chicago, in 1925.
Number 5 was used in the construction of the Wacker Drive improvement in Chicago.
Number 6 was used in concrete pavements in Urbana, Ill., 1926.
Number 7 was used in concrete curb and gutter and sidewalk construction in Urbana, 1926.
Number 8 was used in substructure of the Portland Cement Association building.
Number 9 was used in the construction of the Wacker Drive improvement in Chicago.

[1] Tests made by Wm. J. Putnam, at Urbana, Ill., for the Western Brick Company at Danville, Ill. Specimens were 6- × 12-in. cylinders. Each value given is the average of at least three values.

produce greater strengths than the leaner mixes and lower curing temperatures.

Haydite is being used principally in concrete building units and in floor and roof slabs. Other uses are being developed.

Value of Tests on Aggregate

Concrete is a material which is put to many uses. Certain qualities in the aggregates are desirable and necessary in all cases while in others only special qualities are necessary. Clay and silt, for instance, may be tolerated in sand to the extent of 5 per cent by weight for structural concrete but must be limited to about 2 per cent for pavement concrete, while durability is necessary for all kinds of concrete.

Aggregates should be hard to resist grinding action; tough to withstand impact; durable to endure under variable weather conditions; strong to stand up under heavy loads; sound to remain whole during freezing and thawing; clean to permit the cement paste to bond or in order not to contaminate the cement paste; graded to make a workable concrete and one that is economical, or light in weight to make light-weight concrete. Further discussion of these qualities will be made in connection with each test.

Deval Abrasion Test.—It has been found that aggregates which show a low loss in this test will generally be hard, tough, durable, and strong. This test is more generally used than any of the others.

For crushed stone a sample consisting of 50 pieces weighing 5,000 g. is prepared, dried, weighed, and placed in a cylinder of the Deval abrasion machine. The cylinder is 20 × 33 cm. and is set at an angle of 30 deg. with a horizontal shaft. The shaft is rotated at a speed of 30 to 33 r.p.m. for 10,000 revolutions. The sample is washed, dried, and weighed again. The wear value is taken as the percentage of the material which is finer than $\frac{1}{16}$ in. at the conclusion of the test. When gravel is to be tested it is screened into four sizes and a charge of six small cast-iron spheres from the brick rattler are used. Otherwise the method is the same. Some testing has been done with slotted cylinders, and probably as soon as enough correlating data are available, the slotted cylinders will be the standard.

The French coefficient of wear, or the "French coefficient" as it is often called, is found by dividing 40 by the percentage of

TABLE 5.—TYPICAL RESULTS OF PHYSICAL TESTS ON SOME ROCKS[1]

Name of rock	Location	Crushing strength, pounds per square inch	Weight per cubic foot, pounds	Absorption, pounds per cubic foot	Percentage of wear	French coefficient of wear	Hardness	Toughness
Granite	Massachusetts	18,260	166	0.71	2.6	15.4	18.0	9
Granite	Georgia	15,325	163	0.51	4.7	8.5	17.8	6
Granite	Wisconsin		164	0.25	2.4	16.7	18.7	7
Basalt	Virginia		180	0.39	3.2	12.5	17.7	10
Limestone	Indiana	15,330	166	1.00	4.5	8.9	13.3	6
Limestone	Pennsylvania	19,470	161	0.88	4.2	9.5	15.3	6
Limestone	Colorado		168	0.45	4.6	8.7	13.3	6
Sandstone	Ohio		142	1.84	6.2	6.5	14.7	9
Sandstone	Texas		135	6.62	5.8	6.9	13.0	9
Volcanic sandstone	Washington				3.0	13.3	19.3	
Gneiss (granite)	Massachusetts		162	0.75	3.0	13.3	18.7	11
Gneiss (biotite)	Pennsylvania	21,530	165	0.58			19.0	7
Marble	Vermont	7,380	168	0.39	10.6	3.8	6.7	3
Marble	Georgia	11,340	171	0.37	10.6	3.8	10.3	2
Dolomite	Ohio	16,480	167	1.12	3.4	11.8	16.7	6

[1] Chosen from "The Results of Physical Tests of Road Building Rock from 1916 to 1921, Inclusive," *U. S. Dept. Agr., Bull.* 1132.

wear. American practice is favoring the use of the percentage value rather than the French coefficient.

Part of the popularity of this test in comparison with the others is due to the ease of manipulation. The only special apparatus necessary is the abrasion machine and it comes equipped with either two or four cylinders. A greater number of test pieces are used which makes the results more reliable.

Dorry Hardness Test.—The hardness test consists of grinding both ends of a core of solid rock for 1,000 revolutions each on the Dorry hardness machine. The loss in weight per 1,000 revolutions is taken as a measure of its hardness. The French, who originated the test, developed a coefficient of hardness which is found by subtracting one-third the loss in weight per 1,000 revolutions from 20. Concrete used in highway surfaces, sidewalks and warehouse floors may be subjected to considerable grinding at times.

Toughness Test.—The toughness test is made by dropping a 2-kg. weight from various heights on a cylinder of the rock which is 1 in. in diameter and 1 in. long. The first blow falls 1 cm. and each succeeding blow falls 1 cm. more than the preceding one. The height of the blow causing failure is taken as the toughness value. This test is still used. Concrete in pavements, driveways and warehouse floors is subject to considerable impact at times and therefore it is necessary to have an aggregate which will not shatter easily under impact.

Durability.—There is no laboratory test for durability. We know from previous experience in building work what each of the various rocks will do. As a general rule it is advisable to use only those rocks in concrete which will weather well.

Crushing Strength.—Crushing strength determinations are made on cylinders 2 in. in diameter and 4 in. long or on 2-in. cubes. The former is easily prepared with a diamond set core drill and a high-speed cutting tool to trim up the ends. Most rocks have crushing strengths far in excess of anything that may be secured with concrete, so that it is not necessary to make this test, except for informational purposes.

Soundness.—Recently it has been discovered that some rocks which meet all the other requirements disintegrate after repeated freezing and thawing. Aggregate which cannot pass a freezing and thawing test is considered unsound. In case an aggregate cannot be actually frozen and thawed, an accelerated soundness

test has been devised. The aggregate is immersed in a saturated sodium sulfate solution for 20 hours and then heated in an oven at 100°C. for 4 hours, on each of 6 successive days. Not much data is available as yet along this line, but engineers are very much interested and are making studies.

Clay and Silt Test.—In this test a sample of the aggregate under examination is dried, weighed and washed until the wash water runs clean. It is then dried and weighed again. The material washed away during the test is considered as clay and silt.

Small quantities of clay or silt are not harmful to the concrete strengths and engineers generally permit as much as 5 per cent.

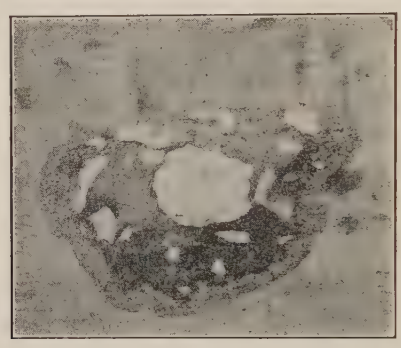


FIG. 36.—Spalling caused by a piece of chert in the aggregate.

In pavement concrete there is a tendency for this material to come to the surface where it causes scaling or is easily worn away leaving a rough surface. Pavement engineers are inclined to limit the percentage to 2 per cent.

Dust or dirt in the coarse aggregate is just as undesirable in the coarse aggregate as in the fine and should be watched as carefully. The limit for coarse aggregate should be only half as great as for the fine aggregate. The limits for both should be so placed that there will not be an excess finally in the concrete. Considerable dust is produced in the crushing and handling of limestone, so that the amount of dust in this material may be excessive. Proper screening or washing will remove it at the plant but will not take care of that which is produced in handling on the job.

Gradation.—Gradation is measured by the sieve-analysis determination. Small representative quantities of the material

are passed through sieves or screens, and the amounts passing or retained on each sieve or screen are determined. It is customary in connection with concrete aggregates to give the values in terms of the entire batch separated on each sieve or screen. In some kinds of work, sieve analyses are given in which the portions between each two sieves or screens are indicated. Results are given as passing or retained. Percentages passing are usually reported although values are usually first secured for the percentages retained.

A graded aggregate is one which contains all sizes of particles between the extreme limits for that kind of aggregate. For fine aggregate the range extends from the 100-mesh sieve to the ¼-in. sieve and for coarse aggregate from the ¼-in. sieve to any maximum size as required by the work in hand. When all of the particles are of one size, it is known as a one-size material. A well-graded aggregate is one containing the proper amounts of the various sizes.

A *sieve analysis curve* is a graphical presentation of a sieve analysis. The diameters of the openings of the sieves are platted to a direct scale as the abscissas and the percentages passing as ordinates. Typical sieve analyses curves are shown in Fig. 42. In some instances the diameters are platted to a logarithmic scale and in other cases the percentages retained are platted instead of the percentages passing. Most engineers now are used to the percentages passing and diameters of opening platted to a direct scale.

The separation of the aggregate into two or more sizes is for the purpose of securing a certain combination of sizes for each batch. For the usual materials available the amount passing a ¼-in. sieve should not be less than one-half the amount which will not go through, in order that the concrete may be workable. On the other hand the amount passing a ¼-in. sieve need not be more than two-thirds the amount not passing, to provide the necessary workability. It is customary to separate the aggregate into fine and coarse sizes in order to be sure that the gradation comes within the above ranges.

Variations in the gradation of the coarse aggregate from batch to batch are often sufficient to change the consistency of the concrete. One state highway department in 1927 required that the coarse aggregate be separated into three sizes and measured as such before being placed in the mixer. On con-

struction work where batches are turned out at regular intervals, it is necessary to secure uniformity from batch to batch without adjusting the amounts of materials each time.

With concrete work done on the basis of the arbitrary proportions it is necessary to require that the aggregate be graded within certain limits, in order that the amount of mixing water

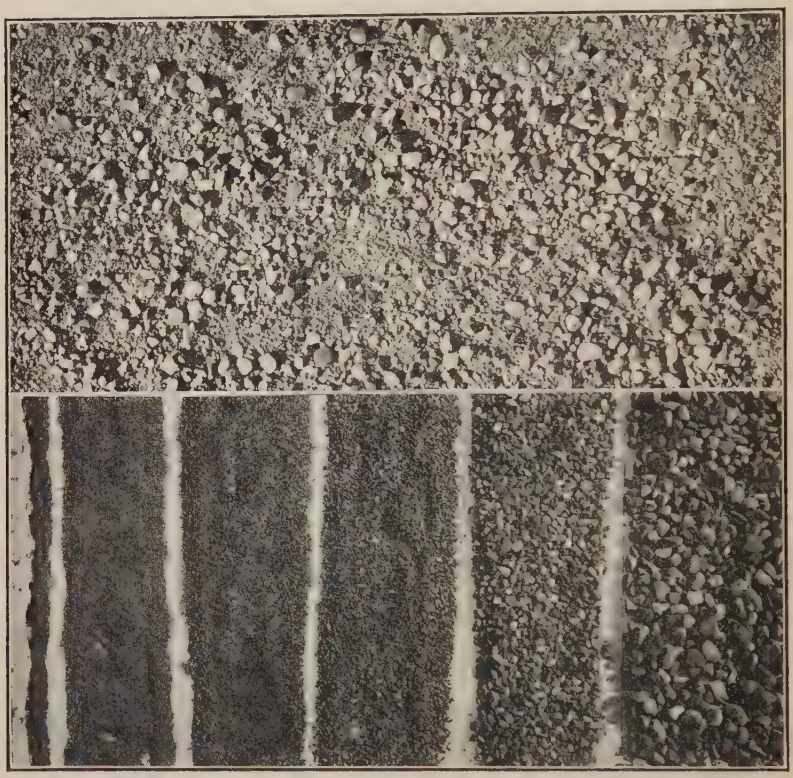


FIG. 37.—*Top*, appearance of a well-graded concrete sand ranging in size up to ¼ in. *Bottom*, appearance of same sand when separated into six different sizes. The width of the strips indicates the relative amounts of each size.

needed will be such as to produce concrete of the necessary strength. For example, take the case of the 1:2:4 mix which is to be used with a slump of 4 in. The amount of aggregate passing the ¼-in. sieve is one-half of that retained on the same sieve. The use of a fine sand will require more mixing water than will a coarse sand. The amount of cement used is the same in either case, hence with the fine sand the cement paste

is diluted more than with the coarse sand and has less strength. Fine coarse aggregate will also require more mixing water than will a coarser gradation. For arbitrary proportioning the gradation of the aggregate should be kept as coarse as possible, but not too coarse to produce workable concrete. If only one gradation of fine or coarse aggregate is available the proportions

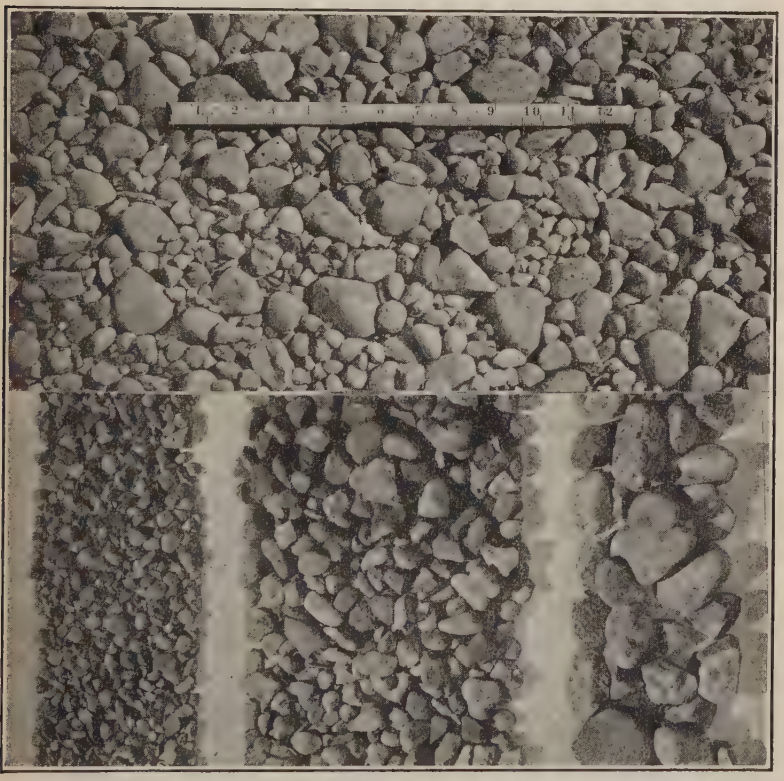


FIG. 38.—*Top*, appearance of a well-graded coarse aggregate ranging in size from ¼ to 1½ in. *Bottom*, appearance of same aggregate when separated into three sizes: ¼ to ⅜ in.; ⅜ to ¾ in.; and ¾ to 1½ in. Width of material indicates amount of each size.

of each should be adjusted so as to give concrete of the desired strength.

When the water-cement ratio is specified the effect of proportions of fine and coarse aggregate is much less. In this method the contractor is required to keep the ratio of water to cement constant and to secure the desired workability by means of the quantity or gradation of the aggregate. The engineer then is

less directly interested in the gradation of the aggregates used. The only requirement is that the concrete be workable. The contractor is desirous of securing as much concrete as possible per bag of cement used. The most concrete is generally secured when the amount of aggregate larger than ¼ in. is from one and one-half to two times the amount finer. Not much difference is noted in the yields for this range. The former will, however, give much more workable concrete.

If it were possible, with arbitrary proportioning, to handle the supervision work easily in the field, probably the best practice would be to specify a gradation for the aggregate as it is to be used and permit the contractor to use any combination of materials which would give him that gradation. It is much easier to control the field operations if the gradations and proportions of fine and coarse aggregate are given, so that it is quite likely that the old procedure will be followed.

Maximum size of aggregate has been mentioned several times without further comment as to the factors affecting its selection. The percentage of voids is decreased as the maximum size of aggregate is increased for a well-graded aggregate. Therefore it is advisable to use a maximum size as large as conditions will permit. The maximum size of aggregate should be limited to about one-fourth the minimum thickness of concrete used or to about one-half the minimum spacing between steel bars. Practically, the maximum size of aggregate used is 2 or 2½ in. In the case of reinforced concrete the problem is to get the concrete around the steel without any honeycombing. The tendency has been to use smaller aggregates than necessary. On massive concrete work large pieces of rock are frequently dropped into the fresh concrete.

The smaller particles give workability to the concrete, but increasing the proportion of these sizes increases the surface area to be coated with cement paste and the volume of voids to be filled. Practice is to make the aggregate as coarse as possible in order that the amount of cement paste may be kept at a minimum or so that the dilution of the paste with water need not be so great. Theoretically all the cement paste that is necessary is enough to fill the voids in the aggregate and coat the surfaces of all the particles. Practically, a small excess is necessary to insure complete performance and to make the finishing operations easier. A balance must be kept between

increased sand content to give workability and increased pebble content to give more concrete.

Specifications

The tentative specifications of the American Society for Testing Materials are quoted in full herewith. Several other sets of specifications for aggregates may be found in the chapter on specifications.

This A. S. T. M. specification is written with the idea that it will be a guide to the engineer writing his specifications rather than a specification which he can just copy or refer to.

Tentative Specifications for Concrete Aggregates

A. S. T. M. Serial Designation C33-28T

This is a Tentative Standard, published for the purpose of eliciting criticism and suggestions, and as such is subject to annual revision.

Issued, 1928

Quality of Aggregates

It is recognized that for certain purposes satisfactory results may be obtained with materials not conforming to these specifications. In such cases the use of fine and coarse aggregates not conforming to these specifications should be authorized only under special provisions based upon laboratory studies of the possibility of designing a mixture of materials to be used on the job that will yield concrete equivalent to the specified mixture made with material complying with these specifications in all respects.

Fine Aggregate

1. *General Characteristics.*—Fine aggregate shall consist of sand or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable particles and shall conform to the requirements of these specifications.

2. *Deleterious Substances.*—(*a*) The maximum percentages of deleterious substances shall not exceed the following values:

	Per Cent by Weight
Removed by decantation	3
Shale	1
Coal	1
Clay lumps	1
Other local deleterious substances (such as alkali, mica, coated grains, soft and flaky particles)	..

NOTE.—It is recognized that under certain conditions maximum percentages of deleterious substances less than those shown in the table should be specified.

(*b*) The sum of the percentages of shale, coal, clay lumps, soft fragments and other deleterious substances shall not exceed 5 per cent by weight.

(*c*) All fine aggregate shall be free from injurious amounts of organic impurities. Aggregates subjected to the colorimetric test for organic impurities and producing a color darker than the standard shall be rejected unless they pass the mortar strength test as specified in Section 4.

3. *Grading.*—(*a*) Fine aggregate shall be well graded from coarse to fine and when tested by means of laboratory sieves[1] shall conform to the following requirements:

	Per Cent
Passing a ⅜-in. sieve	100
Passing a No. 4 sieve	(85) to (100)
Passing a No. 16 sieve	(45) to (80)
Passing a No. 50 sieve	(2) to (30)
Passing a No. 100 sieve	(0) to (5)

NOTE.—Figures in parentheses are suggested as limiting percentages but they may be altered within these limits to suit local conditions.

(*b*) In case the concrete resulting from a mixture of aggregates approaching the extreme limits for gradation is not of a workable character, or when finished does not exhibit a proper surface, due to an excess of particles approximately ⅛ to ½ in. in size, either a fine aggregate having a sufficiently greater percentage of fine material, or a coarse aggregate having a sufficiently smaller percentage of fine material must be used.

4. *Mortar Strength.*—Fine aggregates, when subjected to the mortar strength test, shall have a tensile or compressive strength at the age of 7 and 28 days of not less than (100)[2] per cent of that developed by mortar of of the same proportions and consistency made of the same cement and standard Ottawa sand.

COARSE AGGREGATE

5. *General Characteristics.*—Coarse aggregate shall consist of crushed stone, gravel, blast-furnace slag, or other approved inert materials of similar characteristics, or combinations thereof, having hard, strong, durable pieces, free from adherent coatings and conforming to the requirements of these specifications.

6. *Deleterious Substances.*—(*a*) The maximum percentages of deleterious substances shall not exceed the following values:

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[1] For detail requirements for these sieves, see the Standard Specifications for Sieves for Testing Purposes (Serial Designation: E11) of the American Society for Testing Materials, 1927 Book of A. S. T. M. Standards, Part II, p. 917.

[2] Percentages in parentheses are recommended but they may be altered to suit local conditions.

	Per Cent by Weight
Removed by decantation	1
Shale	1
Coal	1
Clay lumps	½
Soft fragments	5
Other local deleterious substances (such as alkali, friable, thin, elongated, or laminated pieces)	..

NOTE.—It is recognized that under certain conditions maximum percentages of deleterious substances less than those shown in the table should be specified.

(*b*) The sum of the percentages of shale, coal, clay lumps and soft fragments shall not exceed 5 per cent by weight.

7. *Grading.*—(*a*) Coarse aggregate shall be well graded, between the limits specified, and shall conform to the following requirements:

	Per Cent by Weight
Passing.....in. Sieve[1] or Screen (maximum size)	not less than (95)
Passing.....in. Sieve[1] or Screen (intermediate size)	not less than (40)
(one-half maximum size)	not more than (75)
Passing.....in. Sieve[1] or Screen (intermediate sizes)	not less than.....
(as needed)	not more than.....
Passing No. 4 Sieve or a ¼-in. Screen	not more than (10)

NOTE.—Where a range is shown the engineer should use an appropriate figure within the limits recommended. The percentages in parentheses are recommended but may need to be altered to suit local conditions.

(*b*) In case the concrete resulting from a mixture of aggregates approaching the extreme limits for gradation is not of a workable character, or when finished does not exhibit a proper surface, due to an excess of particles approximately ⅛ to ½ in. in size, either a fine aggregate having a sufficiently greater percentage of fine material, or a coarse aggregate having a sufficiently smaller percentage of fine material shall be used.

8. *Weight of Slag.*—Blast-furnace slag that meets the grading requirements of these specifications shall conform to the following minimum weight requirements:

Base concrete	65 lb. per cu. ft.
Surface concrete (subject to abrasion)	70 lb. per cu. ft.

[1] The question whether round or square openings shall be used for testing aggregates is now being studied by the Section on Coarse Screens of the Technical Committee on Size and Shape of Committee E-1 on Methods of Testing.

9. *Durability.*—Coarse aggregate shall pass a sodium sulfate accelerated soundness test, except that aggregates failing in the accelerated soundness test may be used if they pass a satisfactory freezing and thawing test.

NOTE.—Many engineers feel that an abrasion test for coarse aggregate to be used in concrete subject to abrasion is important, but no test limits are specified, due to the status of knowledge concerning suitable specification limits for this test.

METHODS OF SAMPLING AND TESTING

10. *Methods of Testing.*—The properties enumerated in these specifications shall be determined in accordance with the following methods of test of the American Society for Testing Materials, except as specified in Paragraphs (*e*), (*g*), (*i*) and (*j*).

(*a*) *Sampling.*—Standard Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (Serial Designation: C41)[1]

(*b*) *Sieve Analysis.*—Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C41).[1]

(*c*) *Decantation Test.*—Tentative Method of Decantation Test for Sand and Other Fine Aggregates (Serial Designation: D136-22T).[2]

(*d*) *Organic Impurities.*—Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C40).[1]

(*e*) *Mortar Strength.*—Methods of Making Compression and Tension Tests of Fine Aggregate for Concrete as adopted by the American Association of State Highway Officials.

(*f*) *Compressive Strength.*—Standard Methods of Making Compression Tests of Concrete (Serial Designation: C39).[1]

(*g*) *Soundness.*—Proposed Method of Test for Soundness of Coarse Aggregate (Sodium Sulfate Soundness Test). 1928 Proc. A. S. T. M.

(*h*) *Freezing and Thawing.*—Method of Freezing and Thawing Tests of Drain Tile as described in the Standard Specifications for Drain Tile (Serial Designation: C4).[1]

(*i*) *Shale.*—Proposed Method of Test for Percentage of Shale in Aggregate. 1928 Proc. A. S. T. M.

(*j*) *Soft Fragments.*—Proposed Method of Test for Quantity of Soft Pebbles in Gravel. 1928 Proc. A. S. T. M.

(*k*) Proposed Method of Determination of Coal and Lignite in Sand. 1928 Proc. A. S. T. M.

(*l*) *Moisture.*—Tentative Method of Test for Field Determination of Surface Moisture in Fine Aggregate (Serial Designation: C70-27T).[3]

(*m*) *Consistency.*—Tentative Method of Test for Consistency of Portland-Cement Concrete (Serial Designation: D138-26T).[4]

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[1] 1927 Book of A. S. T. M. Standards, Part II.

[2] Proceedings, Am. Soc. Testing Mats., Vol. 22, Part I p., 802 (1922); also 1927 Book of A. S. T. M. Tentative Standards, p. 501.

[3] Proceedings, Am. Soc. Testing Mats., Vol 27, Part I, p. 800 (1927); also 1927 Book or A. S. T. M. Tentative Standards, p. 229.

[4] Proceedings, Am. Soc. Testing Mats., Vol. 26, Part I, p. 874 (1926); also 1927 Book of A. S. T. M. Tentative Standards, p. 503.

(*n*) *Weight of Slag.*—Standard Method of Test for Unit Weight of Aggregate for Concrete (Serial Designation: C29).[1]

(*o*) *Abrasion.*—If abrasion tests are made the following methods of tests are recommended:

(1) *Abrasion of Gravel.*—Tentative Method of Test for Abrasion of Gravel (Serial Designation: D—-28T).[2]

(2) *Abrasion of Rock or Crushed Slag.*—Standard Method of Test for Abrasion of Rock (Serial Designation: D2),[1] except that for specific gravities lower than 2.2 a 4000-g. sample shall be used.

Questions

1. What materials may be used as mineral aggregate in concrete?
2. What is the usual distinction between fine and coarse aggregates?
3. What is the distinction between gravel (or pebbles) and crushed stone?
4. What are igneous rocks? sedimentary rocks? metamorphic rocks? trap rock?
5. Give characteristics of blast-furnace slag, cinders, and Haydite.
6. What qualities are required for fine aggregate? for coarse aggregate?
7. What qualities do the abrasion tests for aggregates measure? Why should there be different tests for crushed stone and pebbles?
8. Explain reasons for having
   a. graded aggregates
   b. clean aggregates
   c. sound aggregates
   d. aggregates free from organic impurities
9. What would be the effect on the concrete of an insufficient amount of particles in the fine aggregate passing the 50-mesh sieve?

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[1] 1927 Book of A. S. T. M. Standards, Part II.

[2] See 1928 Report of Committee D-4 on Road and Paving Materials.

CHAPTER 5

MIXING WATERS AND ADMIXTURES

Mixing Water

Mixing water for concrete is often restricted to water which is suitable for drinking purposes. Not all water, however, which is unsuitable for drinking is unsatisfactory for mixing water in concrete. No special tests have developed for determining the quality of mixing waters, so that it is difficult for the man in the field to judge the fitness of the water. If there is any question about the water, samples should be sent to a laboratory where they may be compared with water which is known to be satisfactory. The comparison should be made by means of strength tests on mortar or concrete.

Tests were made at Lewis Institute, Chicago, Ill., on a large number of samples of water. The report on these tests says in part:[1]

> . . . in spite of wide variations in the origin and type of waters used, and contrary to accepted opinion, most of the samples gave good results in concrete . . . The following samples gave concrete strengths below the strength ratio of 85 per cent which was considered the lower limit for acceptable mixing waters: acid water, lime soak from tannery, refuse from paint factory, mineral water from Colorado, and waters containing over 5 per cent common salt.

The effect of sugar and similar compounds was not included in the investigation. These are known to reduce the strength considerably and should be avoided.

Hydrated Lime

Hydrated lime is quicklime which has been mixed with about one-third of its weight of water. Quicklime is produced by heating limestone to a temperature of 800°C. or over.

[1] Abrams, Duff A., "Tests of Impure Mixing Waters for Mixing Concrete," *Proc. Am. Concrete Inst.*, Vol. 20 (1924) reprinted as *Structural Materials Research Laboratory of Lewis Institute Bull.* 12.

Hydrated lime is sometimes used as an admixture in concrete to increase its workability and waterproofness.

Production of Quicklime.[1]—A pure limestone corresponds in composition to calcium carbonate ($CaCO_3$) and if heated to a temperature of 800°C. or over is separated into lime (CaO) and carbon dioxide (CO_2). One hundred pounds of limestone will produce about 56 lb. of lime.

Most limestones contain some magnesia, which is then evident in the limes produced. For commercial purposes, however, those limes which contain less than 5 per cent magnesia are marketed as pure or high-calcium limes, and those containing more are known as magnesian limes. Most magnesian limes contain about 30 per cent magnesia. They are slower slaking and cooler than the high calcium limes, and less plastic or smooth.

The limestone may be burned in either an intermittent or continuous kiln. In the intermittent type the kiln is charged, burned, cooled, and the charge withdrawn as a cycle of operation. The process is slow and is used only where the demand for lime is slight and intermittent.

There are several types of continuous kilns: vertical kilns with mixed or separated feeds; and rotary kilns. Limestone and fuel are fed in alternate layers into the vertical kilns with the mixed feed. As the burning process continues lime is drawn off at the bottom and more limestone and fuel are added at the top. In the other type of vertical kiln, the limestone and fuel are kept separate. The heating of the limestone is accomplished by the fuel gases which are passed through the limestone. The latter type of vertical kiln is used more generally than the former. These kilns vary from 35 to 50 ft. in height and 5 to 8 ft. in diameter.

The use of the rotary kiln in the manufacture of portland cement caused lime manufacturers to experiment with its use in the production of lime. The consumption of fuel is high in the rotary kiln and some difficulty is experienced in maintaining the proper temperatures. Users of unhydrated or quicklime, object to anything but lump lime, which is difficult to produce in the rotary kiln. Rotary kilns may be used in the production of lime which is later to be hydrated.

[1] For a more complete discussion, see Eckel, "Cements, Limes and Plasters."

Hydrated Lime.—There are three stages in the process of hydrating lime: (1) grinding of the lump quicklime; (2) mixing with water; and (3) sieving. The extent to which the lump quicklime is ground varies somewhat. In certain plants, the material is reduced only until it passes a ½- or 1-in. sieve, which in others it is all ground so that about 80 per cent will pass through a 50-mesh sieve.

The lime is now ready to be mixed with water, which is done in a pan with agitators, or in a horizontal cylinder. In some cases all the lime and water for a batch are put in the pan or cylinder at one time, while in others not all the lime is added until after part of the batch has been partially mixed. The amount of water necessary for slaking varies with the character of the lime. Approximately 55 lb. is necessary per 100 lb. of high calcium lime and 30 lb. per 100 lb. of magnesian lime.

Following the slaking operation the hydrated lime is placed in bins for 48 hours or more, after which it is ready for use. Before packing, the coarser particles are removed by sieving or air-separating devices.

Bagging.—Hydrated lime is shipped in either heavy, closely woven burlap or duck bags containing 100 lb. each, or in paper bags containing 40 lb.

Specifications.—The A. S. T. M. specifications for hydrated lime are quoted herewith.

Specifications for Standard Hydrated Lime for Structural Purposes

A. S. T. M. Serial Designation C6-24

1. *Scope.*—These specifications cover two classes of hydrated lime: namely, masons' hydrate and finishing hydrate.

2. *Uses.*—*a.* Masons' hydrated lime may be used for scratch or brown coat of plaster, for stucco, for mortar, and for addition to portland-cement concrete.

b. Finishing hydrated lime may be used for any of the purposes enumerated in Paragraph *a* for mason's hydrated lime, and in addition it may be used as an ingredient in the final or white coat of plaster.

Requirements

3. *Masons' Hydrate.*—Masons' hydrated lime shall conform to the chemical and physical requirements herein specified except that for plasticity, specified in Sec. 8.

4. *Finishing Hydrate.*—Finishing hydrated lime shall conform to all chemical and physical requirements herein specified including that for plasticity, specified in Sec. 8.

5. *Chemical Properties.*—*a.* Carbon dioxide.—Carbon dioxide in the sample shall not exceed 5 per cent if the sample is taken at the place of manufacture, or 7 per cent if the sample is taken at any other place. The percentages in both cases are based on the non-volatile portion (see Sec. 9).

b. Calcium and Magnesium Oxides.—Calcium and magnesium oxides shall constitute not less than 95 per cent of the non-volatile portion (see Sec. 9).

6. *Fineness.*—The sample shall leave a residue of not more than 0.5 per cent on a No. 30 sieve, and not more than 15 per cent on a No. 200 sieve (see Sec. 10).

7. *Soundness.*—If the steam has no visible effect on the pat (see Sec. 11), the sample shall be reported as being "sound." If the pat disintegrates, the sample shall be reported as being unsound, and the shipment rejected. If the pat cracks, pops, or shows other minor defects, it shall not be reported as either sound or unsound, but its behavior shall be noted.

8. *Plasticity.*—Finishing hydrated lime shall have a plasticity figure of not less than 200 (see Sec. 13).

Methods of Test

9. *Chemical Analysis.*—The chemical analysis of the hydrated lime shall be made in accordance with the Tentative Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (Serial Designation: C25-27T) of the American Society for Testing Materials.[1]

10. *Fineness.*—Fineness of hydrated lime shall be determined as follows:

One hundred grams of the sample as received shall be placed on a No. 30 sieve which shall be nested above a No. 200 sieve. The material shall be washed by means of a stream of water from a faucet. The washing shall be continued until the water coming through the sieve is clear, but in no case should the washing be continued for more than 30 min. The residues on both sieves shall be dried to constant weight in an atmosphere free from carbon dioxide at a temperature between 100 and 120°C. The weights shall be calculated to percentages of the original sample, the weight of the material retained on the No. 30 sieve being added to the weight of the material retained on the No. 200 sieve to obtain the correct weight of the material retained on the No. 200 sieve.

[1] *Proc. A. S. T. M.*, Vol. 27, Part I, 1927; also A. S. T. M. "Tentative Standards," p. 194, 1927.

The sieves used shall conform to the requirements of the Standard Specifications for Sieves for Testing Purposes (Serial Designation: E11) of the American Society for Testing Materials.

A piece of rubber tubing attached to a water faucet is to be used for the washing. The velocity of the water may be increased by pinching the tubing, but should not be sufficient to cause any splashing of the sample over the sides of the sieve.

Care must be taken not to let water accumulate on the No. 200 sieve, else the openings will become clogged and the operation cannot be completed in 30 min.

11. *Constancy of Volume.*—Constancy of volume shall be determined as follows:

To 20 g. of the sample, 100 g. of standard Ottawa sand shall be added, mixed thoroughly and enough water added to the mixture to make a good plastic mortar of rather dry consistency. This shall be spread on a clean glass plate to form a layer about ¼ in. thick by 4 in. square. The pat shall be of even thickness throughout, and not tapering at the edges. If the mortar is too dry to work well, more water may be added. The pat shall be placed in a closet for 24 hours. The temperature in the closet shall be between 65 and 75°C. (18 and 24°C.), and there shall be free circulation of air, but no direct draft striking the pat. The pat shall then be soaked in water until a film of water stands unabsorbed on the surface of the pat. If the pat has cracked, the consistency of the mortar was too wet and a new pat must be made. Two or three pats made at the same time from mortars of slightly different consistencies will avoid delays.

Twenty grams of the sample shall be mixed with enough water to form a thick cream. This shall be spread in a thin layer on the surface of the pat. It shall be allowed to stand for 15 min. to permit air bubbles to form. It shall be trowelled to an even surface, making this skim coat as thin as possible without allowing the sand to show through. The pat shall be put in the closet, under the conditions specified above, for 24 hours. It shall be examined carefully to see that there are no cracks or pops. The pat shall be suspended in a vessel partially filled with cold water, in such a way that the water can boil without touching the pat. The water shall be brought gradually to boiling and kept boiling gently for 5 hours, the pat being surrounded by steam during this time. The water shall then be permitted to cool for at least 12 hours. The pat shall then be removed and examined.

12. *Consistency.*—Consistency of lime putty shall be measured as follows:

The lime shall be made into a stiff putty with water and permitted to soak over night. It shall be molded in a ring such as is used with a Vicat needle, resting the specimen on a glass plate.

The needle used is a modified form of Vicat needle, 12.5 mm. in diameter and weighing 30 g. This may conveniently be made from a suitable piece of aluminum tubing. The lower end should be closed without shoulders or curvature, and the tube loaded with shot to the specified weight. It is mounted in the Vicat needle stand.

The initial reading shall be taken with the bottom of the needle in contact with the surface of the sample. The final reading shall be taken 30 sec. after the plunger is released. A penetration of 20 mm. shall be considered standard.

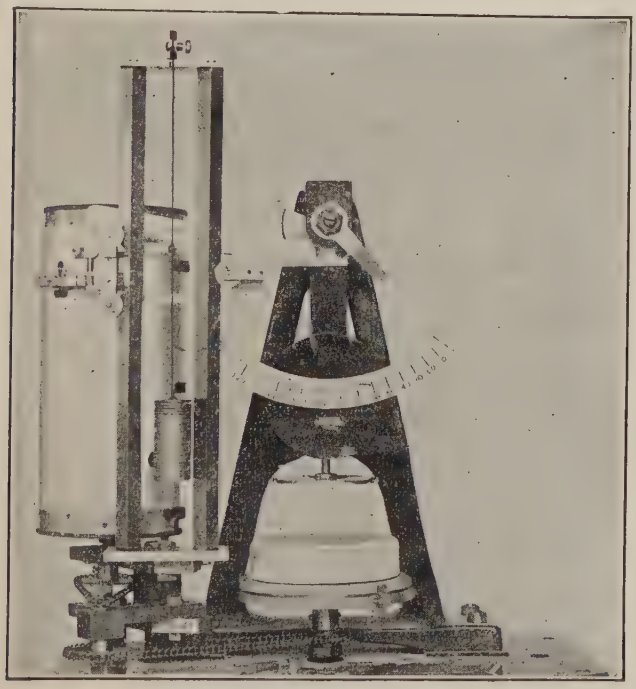


FIG. 39.—Emley plasticimeter.

If the penetration is less than standard, the sample may be removed from the mold, mixed with more water, and retested. If the penetration is more than standard, the sample shall be discarded and a new one prepared.

The ring and the Vicat needle stand are described in the Standard Specifications and Tests for Portland Cement (Serial Designation: C9) of the American Society for Testing Materials.[1]

13. *Plasticity.*—Plasticity shall be determined by means of the apparatus shown in Fig. 39 as follows: Three hundred grams of the sample shall

[1] See Test no. 3.

be mixed with enough water to form a thick putty. After aging in a vessel covered with a damp cloth for not less than 16 nor more than 24 hours, this putty shall be adjusted to standard consistency, as defined in Sec. 12, with a permissible variation of ± 5 mm.

A ring such as is referred to in Sec. 12 shall be lubricated with a thin film of water, placed on a porcelain base plate, filled with the paste and struck off level. The mold shall be removed by raising it vertically without distorting the paste. The base plate and paste shall be placed in the instrument and the carriage turned up by hand until the surface of the paste is in contact with the disk and the distance between the disk and the top of the base plate is $1\frac{1}{4}$ in.

The carriage shall be thrown into gear and the motor started. It is essential that the motor shall be started exactly 120 sec. after the first portion of the paste has been put in the mold. The time when the first portion of paste is put in the mold shall be recorded as zero time—the motor is therefore started at 2 min.

Care shall be taken to protect the specimen from drafts during the test.

The scale reading shall be recorded every minute until the test is completed.

The test shall be considered complete when (*a*) the scale reading reaches 100; (*b*) any reading is less than the one before; or (*c*) the scale reading remains constant for three consecutive readings (2 min.) and the specimen has visibly ruptured or broken loose from the base plate.

The time and the scale reading at the end of the experiment shall be noted. The plasticity figure shall be calculated from the formula $P = \sqrt{F^2 + (10T)^2}$, in which P is the plasticity figure, F is the scale reading at the end of the experiment, and T is the time in minutes from when the first portion of paste was put in the mold to the end of the experiment.

After each test, the porcelain base plate shall be washed with hot water, treated with dilute hydrochloric acid to remove any lime from the surface pores, washed again with water, to remove the acid, dried by heating above 100°C., and cooled to room temperature before it is used again.

Sampling, Inspection, Rejection, Etc.

14. *Sampling, Retesting, Packing, Marking.*—The sampling, retesting, packing and marking shall be conducted in accordance with the Standard Methods of Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (Serial Designation: C50) of the American Society for Testing Materials.

Calcium Chloride

Calcium chloride is used in concrete work for the following purposes:

1. Sprinkled on surface for curing purposes.
2. Mixed integrally for curing purposes.
3. Mixed integrally to lower the freezing temperature of the water and to hasten the early hardening of the concrete.

Production.—Calcium chloride as produced commercially today is derived from one of two sources. In some localities natural brines occur which contain a sufficient quantity of calcium chloride to warrant its extraction on a commercial basis. It is also produced as a by-product in the manufacture of soda, made by the Solvay process. A certain liquor is secured which contains essentially sodium chloride and calcium chloride. In either case commercial calcium chloride is produced by evaporating the water from the concentrated liquors and by a specially patented operation the flake form is obtained.

Specifications.—The A. S. T. M. Specifications for calcium chloride are quoted herewith. The same grade is used for curing of concrete, either integrally or sprinkled on the surface, as is specified for dust prevention.

Tentative Specifications for Calcium Chloride for Dust Prevention

A. S. T. M. Serial Designation: D98-22T

1. *Material Covered.*—These specifications cover calcium chloride to be applied to the surface of highways as a dust preventive.

I. Properties and Tests

2. *Physical Properties.*—The calcium chloride shall be in the form of loose dry lumps or flakes, and fine enough to feed readily through the common forms of spreaders used in road work, and when tested by means of laboratory screens and sieves shall meet the following requirements:

	Per Cent
Passing ⅜-in. screen	100
Retained on ¼-in. screen	not more than 20
Passing No. 20 sieve	not more than 10

3. *Chemical Composition.*—Ten grams of the material dissolved in 100 cc. of boiling water shall show less than 1.0 per cent insoluble

residue. Not more than 1.0 cc. of normal acid shall be required to neutralize the alkalinity of the filtrate, using methyl orange. The chemical composition shall conform to the following requirements:

	Per Cent
$CaCl_2$ (anhydrous)	not less than 73
$MgCl_2$	not more than 0.5
NaCl	not more than 2.0
Other impurities	not more than 1.0

The percentage of calcium chloride shall be calculated from the percentage of calcium in the filtrate above referred to, after making a deduction for the SO_4, which shall be assumed to be in combination as $CaSO_4$.

II. Packages

4. *Packages.*—The calcium chloride shall be delivered in air-tight moisture-proof bags or sacks containing approximately 100 lb. each, or in air-tight steel drums weighing not more than 350 lb. each. The name of the manufacturer, the lot number, the approximate net weight, and the percentages of calcium chloride guaranteed by the manufacturer shall be plainly marked on each container.

III. Inspection

5. *Inspection.*—Every facility shall be provided the purchaser should he elect to have his own representative sample the material at the plant. If the purchaser decides to sample the material after delivery in the field it is understood that a 3 per cent variation in content of $CaCl_2$ from the chemical composition stated in Sec. 3 shall be permissible.

6. *Rejection.*—Calcium chloride shall be rejected if it fails to pass any of the requirements of these specifications and if it has become caked or sticky in the containers before opening.

IV. Basis of Payment

7. *Basis of Payment.*—Payment will be made on the basis of total number of pounds of 100 per cent calcium chloride delivered.

Diatomaceous Silica[1]

Diatomaceous silica is composed of the remains of the simplest form of plant life called "diatoms" which are found in both fresh and salt waters. The diatoms perpetuate themselves by dividing into two complete diatoms every day or two. The microscopic material which forms the body of the deposits of

[1] Celite is the trade name of the product in most common use.

diatomaceous silica is pure silica secreted from the water in which the diatoms lived.

It is thought that the diatoms which form the principal deposit of diatomaceous silica and which is located at Lompoc, Calif., were grown in much colder waters to the north and that the sudden change in temperature which took place as a result of their movement by ocean currents to southern waters caused them to die in large numbers. This deposit covers many square miles and varies in depth from 900 to 1,400 ft. Deposits are

FIG. 40.—A deposit of diatomaceous silica.

covered with earth and rock necessitating extensive operations for their removal.

All deposits of diatomaceous silica contain varying amounts of foreign materials, such as earth or clay, so that care must be exercised in selecting the raw material to be prepared. The diatomaceous silica is ground so that 95 per cent will pass through a 200-mesh sieve and thoroughly mixed so that over 90 per cent is pure silica. The prepared material is extremely light, weighing about 10 lbs. per cubic foot.

Diatomaceous silica is used as an admixture in concrete, principally to improve its workability. The quantity depends

upon the mix and in general more of the admixture should be used in the leaner mixes than in the richer ones. The amounts used are shown in the following table:

Mix	Diatomaceous earth, pounds per bag of cement	
	Limits	Average
1:1½:3	1½ to 3	2
1:2:3½	2 to 4	3
1:2:4	2 to 4	3
1:2½:5	3 to 6	4
1:3:6	4 to 8	5

It is added with the other materials as they are placed in the mixer. (See also the chapter on Workability and Waterproofness for further discussion.)

Specifications.—No specifications for diatomaceous silica have been prepared by the A. S. T. M. Engineers are using the following specifications which are recommended by a producer of this material:

Diatomaceous silica for use in concrete or hydraulic cement composition shall be finely divided Plankton Marine diatomaceous silica substantially free from clay and crystaline silica and shall conform to the following requirements:

1. *Fineness.*—Not more than 8 per cent by weight of the material shall be retained on a 200-mesh sieve.

2. *Weight per Cubic Foot.*—An air-dried sample shall not weigh more than 10 lb. per cubic foot when fluffed through an 8-mesh sieve.

3. *Moisture Content.*—The material shall not contain more than 7 per cent by weight of moisture.

4. *Loss on Ignition.*—A moisture-free sample of the material shall not show a loss on ignition at 1800° of more than 7 per cent.

5. *Silica and Alumina Content.*—An ignited sample shall contain at least 91 per cent of silica and not over 4 per cent of alumina.

6. *Settling Test.*—Settling tests with distilled water shall show not less than 55 per cent of the material remaining in suspension after 20 min.; and after 5 hours settling tests shall show not more than 28 nor less than 16 per cent remaining in suspension.

Questions

1. What kind of water may be used for mixing water in concrete?
2. What is quicklime? hydrated lime? Describe manufacture of each.
3. Give reasons for use of hydrated lime in concrete. Why can not quicklime be used?
4. What is calcium chloride? Give reasons for its use in concrete.
5. What is diatomaceous silica? Give reasons for its use in concrete.

CHAPTER 6

THEORIES OF PROPORTIONING

Concrete is a material composed of cement, water, and mineral aggregate which develops strength with age. Strengths are influenced by many factors, such as quality and quantity of cement, water and aggregates, thoroughness of mixing, temperature of unmixed materials and of the concrete during and after placing, and the method of curing. The determination of the proper amounts of given materials to use to produce, at a certain age, concrete of a given strength under given conditions of mixing, placing and curing is known as proportioning.

In the early days of concrete, strengths were low at 7 to 10 days with the result that all strength tests were made at ages of 28 days or greater. The tendency has always been to develop greater strengths at earlier ages but until recently the practice has been to make the tests only at 28 days. Since the World War special efforts have been made to develop what is known as high early strength concrete (see Chap. 11) so that today many strength tests are being made at ages under 28 days.

From the number of factors enumerated above it is apparent that no mathematical formula may be developed from which the strength of concrete may be predicted for any combination of conditions. A number of investigations have been carried out at various times to determine a basis for proportioning but in each case certain items were not varied and today we cannot be certain of our field strengths until after tests have been made.

In this chapter are presented brief summaries of the scope, the methods used, and the results of major investigations of concrete proportioning, and information concerning empirical and trial proportioning. Since the studies were all made under laboratory conditions and as indicated before, not all of the variables present in the field were included, it is not possible to predict field strengths accurately from these results. Certain information of value may be secured from each investigation

and if conditions under which the tests were made are borne in mind, no great conflict of ideas will result. The quality of the cement has been improved since the last of the investigations were made, and the strength curves are lower than can be expected today.

Empirical Proportioning.—The oldest and most used form of proportioning is that in which the amounts of the dry materials are arbitrarily selected. This method has in a general way proved satisfactory and is likely to be extensively used for some years to come because of the simplicity of its application and

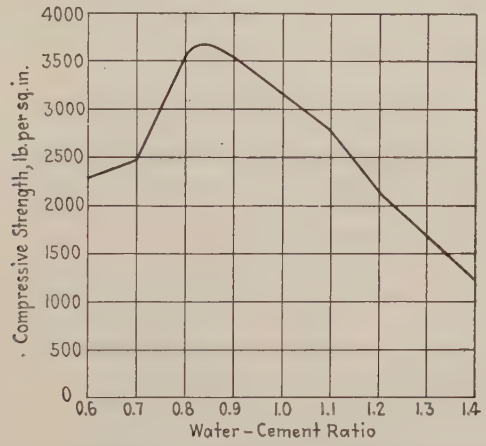


FIG. 41.—Relation between amount of mixing water and compressive strength for a 1:2½:4 mix. Batches with water-cement ratios less than 0.9 were not workable, although the one with the 0.8 ratio was not particularly so.

Each point platted is the average value for 15 cylinders, 3 of which were made on each of five different days. The concrete was machined mixed, molded in the standard manner, cured in a moist room at 70°F., and tested at 28 days.

because more people are familiar with it than with any other method. On larger and more important work where money is available for supervision, strengths are being specified and tests made. Where empirical proportioning is used, the qualities and quantities of the cement and aggregate are specified for each. The exact amount of water, however, is not given, it being intended that the desired consistency shall be obtained by varying the amount of mixing water. Some control over the amount of mixing water is exercised when the consistency of the concrete is specified. On jobs where the consistency is not carefully controlled, wide variations in strength may result from the use of different amounts of mixing water. The curve in Fig. 41

shows how much the strength of a 1:2½:4 mix may be varied by the use of different amounts of mixing water. The batches with water-cement ratios less than the one giving maximum strength are too dry and are not considered workable. For arbitrary proportions the amount of mixing water should be kept at a minimum in order to secure the greatest amount of strength.

Proportions commonly used for various classes of work are:

Reinforced concrete	1:2:4	or 1:2½:4
Mass concrete	1:3:5	or 1:3:6
Pavement concrete	1:2:3	or 1:2:3½
Pavement bases	1:2½:4	or 1:3:5
Sidewalks	1:2:3	or 1:2:4

Fuller and Thompson's Studies

William B. Fuller and Sanford E. Thompson made some studies about 1905 of the effect of different gradations of aggregate upon

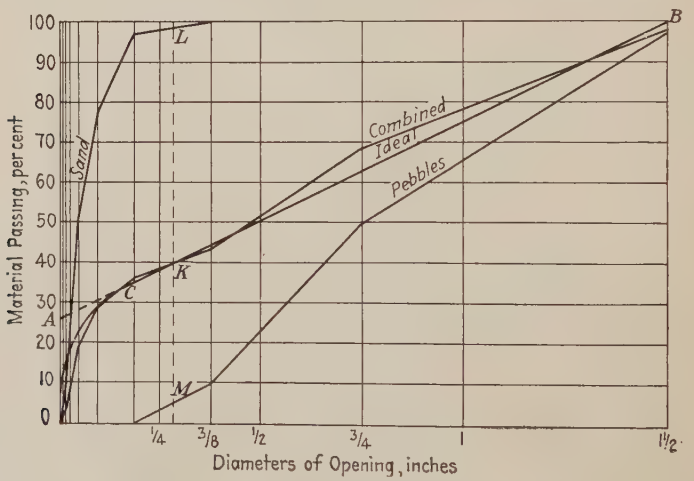


Fig. 42.—Combination of two aggregates to agree with Fuller's ideal curve.

strength and density of the concrete produced. Most of the work was done in connection with the Jerome Park Reservoir in the Bronx district, New York.[1]

At that time aggregate was used as it came from the pit or from the stone crusher, no attempt being made to separate the

[1] Fuller and Thompson, "The Laws of Proportioning Concrete," *Trans. Am. Soc. of Civil Eng.*, Vol. 59, pp. 67–143.

aggregate into two sizes such as we do now. The aggregate usually contained an excess of fine material and it was the purpose of the authors to determine a gradation of aggregate which under average conditions would be the best. An ideal sieve analysis curve, since known as Fuller's ideal curve, was developed. Data for platting these curves is given in Table 6 and the curve for a combination of sand and pebbles is shown in Fig. 42.

TABLE 6.—DATA FOR PLOTTING FULLER'S IDEAL CURVE

Materials	Intersection of tangent with vertical at zero diameter, point *A* in Fig. 42	Height of tangent point, point *C* in Fig. 42	Axes of ellipse	
			a	*b*
Crushed stone and sand	28.5	35.7	1.150D[1]	30.4
Pebbles and sand	26.0	33.4	0.164D[1]	28.6
Crushed stone and screenings	29.0	36.1	0.147D[1]	30.8

[1] *D* is the maximum diameter.

At the time of Fuller's work the mixes in common use were rather lean. The ideal curve as shown in Fig. 42 is for all the dry materials, including the cement. If we were to use the curve today with the rich mixes now common, the proportion of sand would be low and the concrete might be harsh and unworkable. The present tendency is to increase workability by using larger amounts of fine material thus making Fuller's ideal curve impractical.

Example of Use of Ideal Curve.—Given sand and pebbles aggregates whose sieve analyses are given in Table 7 and whose curves are platted in Fig. 42. The problem is to combine these two materials in such a way that the curve of the combined materials will approximate the ideal curve as shown. Probably the easiest way is to try a number of combinations and select the one agreeing most closely.

For the first trial, try a combination of 40 per cent sand and 60 per cent pebbles. Tabulate the sieve analysis values for each material, as shown in Table 7. To figure the sieve analysis of the combination assume that a batch of 100 lb. is being used, of which 40 lb. are sand and 60 lb. pebbles. Based on the sieve analyses of each material figure the weights of sand and pebbles passing each of the sieves, as given in columns 4 and 5. Add values in columns 4 and 5 and record as in column 6. Figure percentages for values

in column 6 and record as in column 7. Plat curve for combined aggregate. If this curve does not agree closely with the ideal curve, try another combination. In this case, a combination of 37 per cent of sand and 63 per cent of pebbles aggrees most closely to the ideal curve.

The ideal curve was worked out to produce maximum density of the dry materials and when used the percentage of cement is subtracted from the value found above for sand to get the actual value for the latter. Much more workable concrete may be secured if the percentage of sand is used as determined.

TABLE 7.—COMPUTATION OF SIEVE ANALYSIS OF COMBINED AGGREGATE

Sieve designation	Sieve analysis, individual materials, per cent passing		Combined aggregate,[1] weights passing, pounds			Combined aggregates, percentages passing[2]
	Sand	Pebbles	Sand	Pebbles	Combined	
100	4	0	1.6	0	1.6	2
48	10	0	4.0	0	4.0	4
28	25	0	10.0	0	10.0	10
14	51	0	20.4	0	20.4	20
8	78	0	31.2	0	31.2	31
4	97	0	38.8	0	38.8	39
⅜-in.	100	10	40.0	6.0	46.0	46
¾-in.	100	50	40.0	30.0	70.0	70
1½-in.	100	97	40.0	58.2	98.2	98

[1] Total weight 100 lb. composed of 40 lb. of sand and 60 lb. of pebbles.
[2] Percentages are recorded to the nearest whole per cent.

General Observations.—Certain observations about strength and imperviousness were made by the writers and have since been quoted many times. The first observation was that, other things being equal, the concrete with the greater amount of cement in it would be the stronger. Investigations since Fuller's indicate that the concrete with the smaller water-cement ratio will be the stronger even though the amount of cement may be less. Ordinarily, for instance, a 1:2:3½ mix will have more cement than a 1:2:4 mix and will be stronger provided the consistencies are the same. It is possible, however, for more mixing water to be used in a 1:2:3½ than in a 1:2:4 mix, in which case the latter will be the stronger, and the consistency of the former will be much wetter. Or, if the same water-cement ratio is used in both, they will be of essentially the same strength.

The second observation was that, other things being equal, the densest concrete would be the strongest and most impermeable. Density alone is not a measure of strength or impermeability. Two concretes of the same density may have strengths far apart. Fuller was varying the gradation of the aggregate, but keeping the ratio of cement to total aggregate constant so that as the density changed, the amount of mixing water had to be varied to produce the same consistency. With greater densities secured through gradation less mixing water was needed, which in turn reduced the water-cement ratio and increased the strength. With the increase in strength the resistance to flow of water was greater.

Fuller and Thompson made no effort to determine a method of estimating concrete strength, their work being entirely with the aggregates. The amount of cement to use was left to the judgment of the person determining the proportions. The investigators observed, as previously noted, that with greater amounts of cement the strength of the concrete was increased. Average strengths were determined for the various mixes in common use and these were then taken as the basis for the selection of the cement factor.

Abrams' Studies

About 1915, or approximately 10 years following Fuller and Thompson's work, the manufacturers of portland cement, through the Portland Cement Association, established a laboratory at Lewis Institute, Chicago, with Duff A. Abrams in charge, for the purpose of studying concrete problems. For a number of years, various individuals had been advancing different ideas about the factors affecting the strength of concrete. The first study undertaken by the new laboratory was one to determine the relationship between mixing water, gradation of aggregate, and richness of mix, and thus settle the controversy. Other items such as quality of cement and aggregates, method of curing, curing temperatures, and age were kept constant. The cement used was a mixture of four brands available on the Chicago market. The aggregates were from Elgin, Ill., and consisted of sand and pebbles. Results were published in 1918 in *Bull.* 1 of Lewis Institute, entitled "The Design of Concrete Mixtures."

The most important result of the investigation was the principle that "with given concrete materials and conditions of test, the quantity of mixing water used determines the strength of the concrete, so long as the mix is of a workable plasticity."[1] The quantity of mixing water is expressed by a new term, the water-cement ratio, which is the ratio of the volume of mixing water to the bulk volume of cement. For a water-cement ratio of 1, 7½ gal. of water are used per sack of cement.

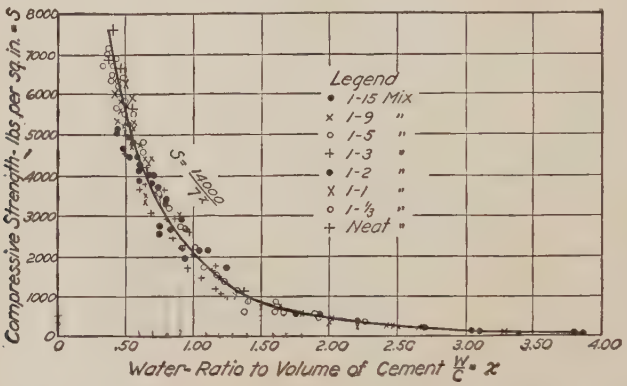


FIG. 43.—Relation between water-cement ratio and compressive strength as determined by Abrams.

This curve is based on test specimens made under laboratory conditions and with a mixture of four cements. Since these tests were made the manufacturers generally have increased the quality of their cements, so that today this is a conservative curve. The concrete was made and cured at a temperature of approximately 70°F.

For the materials used and the conditions of the tests, Abrams found the following relationship to exist between water cement ratio and strength:

$$S = \frac{14{,}000}{7^x},$$

in which S = strength in pounds per square inch at 28 days, and x = the water-cement ratio, and which is shown graphically in Fig. 43. The water-cement ratio-strength law holds true regardless of the gradation of the aggregate, the mix, or the consistency, so long as the concrete is workable. It must be remembered that this law is based on laboratory tests with given materials and is indicative of the results which may be expected with other materials and conditions, the curves being higher or lower as other factors influence the values. Field

[1] ABRAMS, D. A., "Design of Concrete Mixtures," Structural Materials Research Laboratory. Bull. 1.

test results can not be predicted accurately from laboratory test results so that when Abrams' work was given a field application wide variations in strength were secured where uniform results were expected. The trouble was not in what had been done in the laboratory, but in that certain factors were influencing the field results which were not considered in the laboratory tests. Experience gained in field testing is enabling many engineers to estimate concrete strengths much better than formerly.

Fineness Modulus.—A method of calculating the amounts of materials to use for any given strength and consistency is also

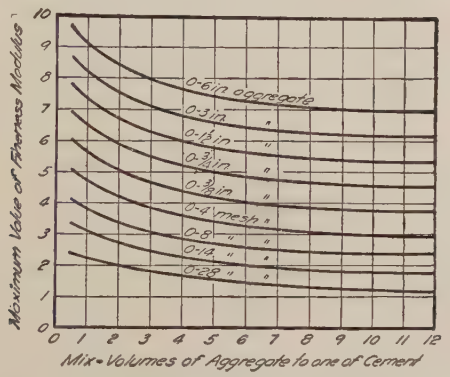


FIG. 44.—Maximum permissible values of fineness modulus.

The curves in this figure are for rounded gravel and sand. For other materials see *Bull.* 1 of Lewis Institute.

included in the bulletin, and is based on a function of the aggregate known as fineness modulus, which is found by dividing by 100 the sum of the percentages in the sieve analysis retained on the Nos. 100, 48, 28, 14. 8, and 4, and the ⅜-, ¾-, and 1½-in. Tyler sieves. The same value of fineness modulus may be obtained from a number of different gradations. Fineness modulus values for sand vary from about 1.50 to 3.75 and for pebbles from 5 to 8. Fineness modulus values for combinations of the above materials will vary between the values of each, depending upon the proportion of each.

Example of Use of Abrams' Method.—A specific case is included in the illustration as well as the general instructions.

1. Select strength and consistency.

2,500 lb. per square inch.
1:2 Relative consistency.

2. Determine by actual tests the fineness modulii of aggregates to be used.

Values: Sand = 2.90
Pebbles = 7.00

3. Determine maximum size of aggregate from sieve analysis data, according to the rule: "The maximum size of aggregate is designated as the smallest sieve having a value of between 0 and 15 per cent in the sieve analysis."

Maximum size: 1.5 in.

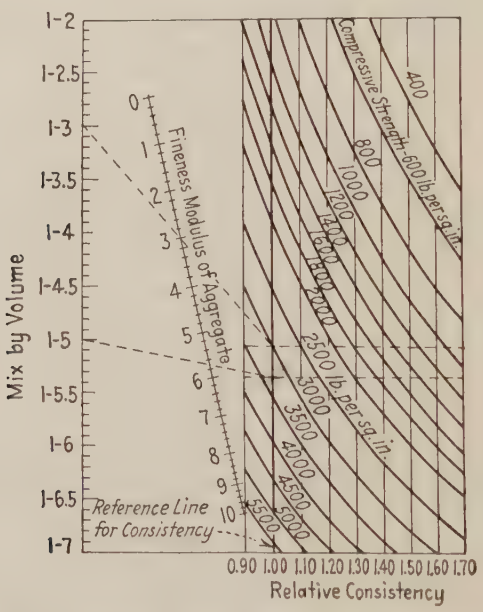


Fig. 45.—Diagram for the design of concrete mixtures.

This chart is based on compression tests of 6 by 12-in. cylinders; age 28 days; stored in damp sand.

The cement used gave compressive strengths in 1:3 standard sand mortar as follows, when tested in the form of 2 by 4-inch cylinders:

Age	Pounds per Square Inch
7 days	1,900
28 days	3,200
3 months	4,200
1 year	4,300

4. Estimate a mix which is likely to give the correct strength at the desired consistency.

Estimated mix 1:5

5. Determine from Fig. 44 the maximum permissible value of the fineness modulus of the combined aggregate.

Fineness modulus = 5.75

6. Check in Fig. 45 to see if the mix selected will give the correct strength at the desired consistency. Place straight edge on the mix by volume (1 to

5) at the left and on fineness modulus of aggregate (5.75) and note value of strength on the vertical line at relative consistency of 1.00. Lay straight edge perpendicular to vertical lines and read value at desired consistency (1.2). In this case it is 2,400 lb., slightly under that originally selected. This is close enough, however.

7. In case the mix chosen in step 4 is not correct, repeat steps 4, 5, and 6 until the correct mix is selected.

8. The proportion of fine and coarse aggregate by weight is then computed from the formula

$$P = \frac{A - B}{A - C} \times 100$$

in which

P = percentage of fine aggregate.
A = fineness modulus of coarse aggregate.
B = fineness modulus of combined aggregate.
C = fineness modulus of fine aggregate.

The percentage of coarse aggregate is equal to 100 minus the percentage of fine aggregate.

$$P = \frac{7.00 - 5.75}{2.00 - 2.90} \times 100 = 30.5 \text{ per cent}$$

9. Determine the weight per cubic foot of the sand, pebbles, and a combination of these materials as determined in step 8.

Weight sand = 108.0 lb. per cubic foot
Weight pebbles = 102 lb. per cubic foot
Weight combination = 120.0 lb. per cubic foot

10. Figure proportions by volume: 5 cu. ft. (from steps 4, 5, and 6) of combined aggregate weighs 600 lb. 30.5 per cent is sand, which weighs 183 lb. The balance is pebbles and weighs 417 lb.

$$\frac{183 \text{ lb.}}{112 \text{ lb. per cubic foot}} = 1.63 \text{ cu. ft.}$$

$$\frac{417 \text{ lb.}}{102 \text{ lb. per cubic foot}} = 4.09 \text{ cu. ft.}$$

The proportions by volume are 1:1.63:4.09 which may give harsh and unworkable concrete, especially if no allowance is made for bulking of the sand. If such is the case the proportions of sand and pebbles should be changed to give a workable mix. The amount of mixing water as determined in the next step should not be changed, however.

14. Determine the amount of mixing water to use from the formula

$$S = \frac{14{,}000}{7^x},$$

or from the curve in Fig. 43. Water absorbed by the aggregate is not considered as mixing water.

Comments.—This method is satisfactory for well-graded aggregates, but occasionally harsh and unworkable concretes are obtained. The maximum permissible value of the fineness modulus may be too large for the aggregates to be used or for the work to be done, in which case the value should be reduced. The

idea advanced by Abrams that the gradation of the aggregate was immaterial as long as the fineness modulus was correct has never been generally accepted by engineers. The tendency today is to proportion, by observation, the fine and coarse aggregates to give satisfactory workability. The amount of coarse aggregate should be as large as possible, however. Because of the emphasis placed on the value of increasing the coarseness of the aggregate, many engineers have used too much coarse aggregate with harsh and unworkable mixes resulting. Failure to allow for bulking of the sand due to moisture has also aided in producing this result.

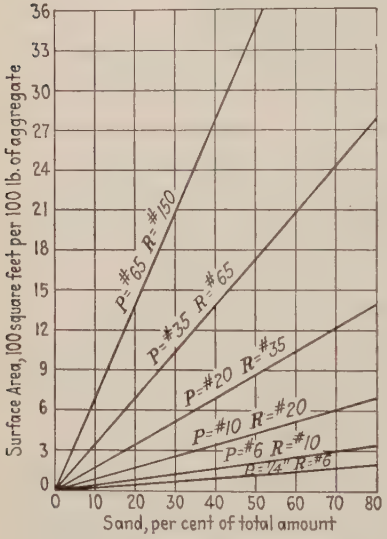


FIG. 46.—Relation between sand grading and surface area.

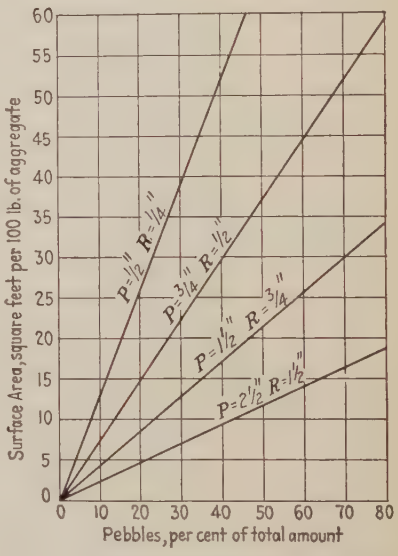


FIG. 47.—Relation between pebbles grading and surface area.

WORK OF EDWARDS AND YOUNG

During 1918, L. N. Edwards, then bridge engineer for the city to Toronto, Canada, published[1] the results of some tests he had made to develop information (1) relating to the average surface areas of sand and stone aggregates; and (2) concerning the practicability of proportioning cement and aggregate on the basis of the surface area of the latter.

The first problem was to determine the approximate average surface areas of the various sizes of aggregate. Small quantities

[1] EDWARDS, "Proportioning the Materials of Mortars and Concretes by Surface Area of the Aggregates," *Proc., A. S. T. M.*, Vol. 18, part II.

of each size of aggregate were weighed out, the number of particles counted, the average volume of particles determined, and then the surface area of a sphere of an equivalent volume computed. In Figs. 46 and 47 are given the results of the surface areas as determined by Edwards. Surface areas are given in square feet per 100 lb. of aggregate for various percentages of each size of materials.

Mr. Edwards came to the conclusion that it was possible to proportion cement and aggregates on the basis of the surface

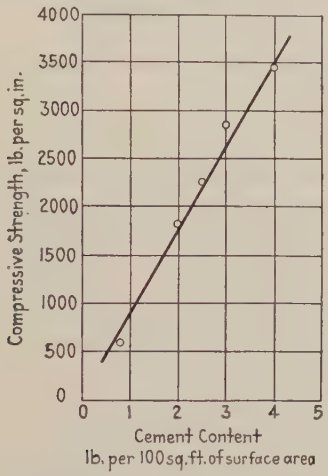


FIG. 48.—Typical curve showing relationship between cement content (in pounds per 100 sq. ft. of surface area) and compressive strength, for concretes of normal consistency (slumps of about 1 in.). For other consistencies other curves must be established.

area of the aggregate. Aggregate must however be uniform in quality and be graded. The method would not work for unusual gradations of aggregate or for non-uniform materials.

R. B. Young has made a practical application of the ideas of both Edwards and Abrams in connection with hydro-electric power development in the Province of Ontario, Canada. For the materials used satisfactory results were secured. Mr. Young accepts the water-cement ratio idea of Mr. Abrams, but prefers to determine the amount of aggregate to use on the basis of surface area rather than fineness modulus.

Mr. Young first made tests to determine the relation between water-cement ratio and compressive strength for conditions as they existed on his work. Such a curve would be similar to the

one in Fig. 43, which was established by Abrams. Then other curves similar to the one in Fig. 48 would be developed for various consistencies, which would show the relationship between strength and cement content per unit of surface area of the aggregate. The curve shown is for a consistency represented by a slump of 1 in. Curves for mixes with greater slumps would be lower.

Examples of Use of Surface Area Method.—1. Select strength and consistency.

2,500 lb. per square inch.
Consistency, slump of 1 in.

2. From Fig. 43 or from curve based on your own test data, determine water-cement ratio to use.

Value = 0.85

3. Figure surface area of aggregate as it is to be used.
This value should be in square feet per 100 lb. of aggregate.

Value = 503 sq. ft. per 100 lb.

4. From Fig. 48, determine weight of cement per 100 sq. ft. of surface area. Value 3 lb. For 503 sq. ft. (100 lb. of aggregate) 15 lb. of cement is necessary.

5. The proportion is 15:100 or 1:6⅔. The 6⅔ parts of aggregate are both fine and coarse mixed. There is no way of determining the proper amounts of fine and coarse aggregates.

The surface area per 100 lb., of the aggregate can be reduced by decreasing the proportion of fine and increasing the amount of coarse particles. By reducing the surface area per 100 lb. of aggregate, the cement content can also be reduced. There is of course a limit beyond which the concrete becomes harsh and unworkable. The answer to the questions of how much should be fine and how much coarse is left to the judgment of the user of the concrete.

It will be noted that the proportion for 2,500-lb. concrete as determined by Abrams was 1:5 and by Edward's method was 1:6⅔. This is due to the difference in consistencies used, the latter requiring much less mixing water.

Talbot and Richart's Studies

Professor A. N. Talbot of the University of Illinois became interested in the problem following the publications by Abrams and Edwards. He was assisted by Frank E. Richart, Research Assistant Professor in the Department of Theoretical and Applied Mechanics at the University of Illinois.[1] The strength of the concrete was found to be dependent upon the composition of the

[1] Results are published in "The Strength of Concrete—Its Relation to the Cement Aggregate and Water," *Eng. Expt. Sta. Univ. Ill. Bull.* 137.

cement paste, considering that the cement paste occupied all the space in the concrete not filled with aggregate. A unit volume of concrete or mortar is the basis for all the discussion. The proportion of cement in the cement paste (called by the investigators the cement-space ratio) may be represented by the expression $\frac{c}{v+c}$, in which c is the solid volume of cement in a unit volume of concrete, and v is the volume of voids in a unit volume of concrete, and $v + c$ is the volume of cement paste in a unit volume of concrete. The volume of the concrete

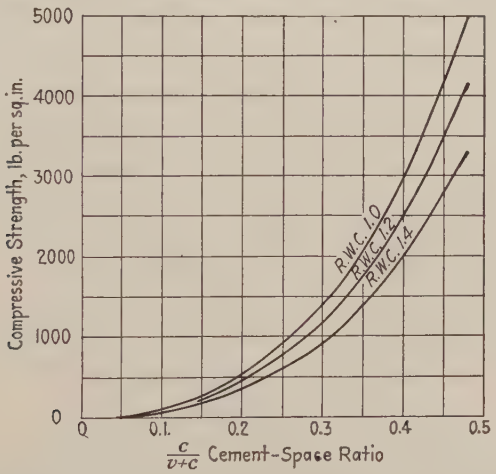


FIG. 49.—Relation between cement-space ratio and compressive strength.

is equal to the volume of cement paste plus the solid volume of the aggregate. The problem then is to find the cement-space ratio for any given concrete in order to estimate its strength, or to find which combination of materials will give the desired cement-space ratio. The relation between cement-space ratio and strength for the tests made by the investigators is given in Fig. 49.

When a given combination of cement and sand is mixed with various amounts of water, different quantities of mortar are produced. As the amount of water is increased from zero, there is at first an increase in the volume of mortar produced, then a decrease until a minimum amount is produced, which is followed by an increase again as shown in Fig. 50. The water content which produces minimum volume is called basic-water content. Mortars with water contents less than basic are not

workable and cannot be used. At any of the water contents the composition of the mortar can be figured.

For any given cement and sand, basic-water content is determined experimentally for a number of proportions of cement and sand, ranging from about equal parts of each to 4 of sand and 1 of cement. Composition of the mortars at basic-water content and at greater water contents, usually 20 and 40 per cent, are figured and data platted as in Fig. 51. The coarse aggregate is considered as filler for the mortar, so that the volume of the concrete is equal to the volume of the mortar plus the solid volume of the coarse aggregate.

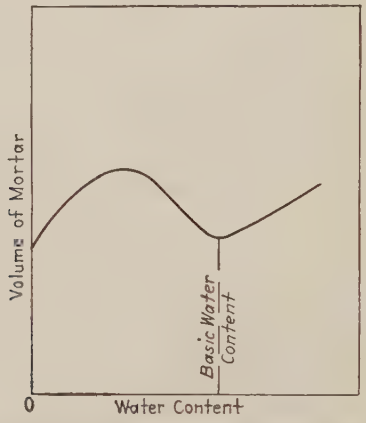


FIG. 50.—Typical curve showing relationship between water content of mortars and the volume.

In studying the results of the tests Professors Talbot and Richart segregated the strength values according to the water content of the concrete. It was found that the wetter mixes had less strength than the drier ones, even though the cement space ratio was the same. The curves shown in Fig. 49 are for concretes and mortars at basic-water content 1.2 and 1.4 times basic. When the water content is 20 per cent greater than at basic-water content the strength values are 85 per cent of those shown and when the water content is 40 per cent greater, the values are reduced to 67 per cent of those at basic water content.

For practically all workable mixes the voids in the concrete are filled with water, so that it is easy to estimate the cement-space ratio when the amount of mixing water is known. For

the drier consistencies used occasionally in pavement work, there may exist a very small amount of air voids. It is safe, as a general rule, to neglect these, and assume that the water fills all the voids. For a one-bag batch in which 7½ gal. (1 cu. ft.) of mixing water are used per bag, the cement-space ratio, $\frac{c}{v+c}$, is 0.333, the solid volume of cement being approximately one-half the bulk volume. Strength results secured by these investigators are lower than those reported by Abrams.

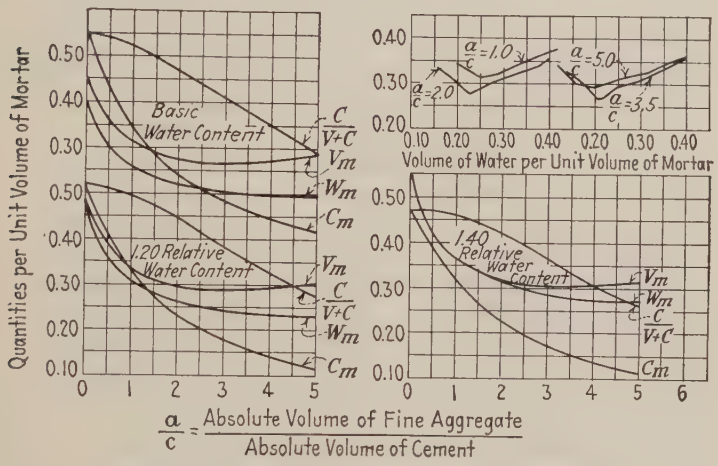


FIG. 51.—Characteristic curves for a coarse sand.

Example of Use.—1. Select strength and consistency. Values selected: strength 2,500 pounds per square inch and consistency or relative water content as designated by Professor Talbot, 1.2.

2. Make series of mortar-voids tests and plat results as shown in Fig. 51.

v_m is the proportion of voids in the mortar.

w_m is the proportion of water in the mortar.

c_m is the proportion of cement in the mortar.

$\frac{c}{v+c}$ is the proportion of cement in the cement paste.

a is the proportion of fine aggregate in the concrete.

b is the proportion of coarse aggregate in the concrete.

c is the proportion of cement in the concrete.

3. Select from Fig. 49 the value of $\frac{c}{v+c}$ which gives the desired strength at the required consistency. Value = 0.400.

4. From Fig. 51 determine the value of a/c which corresponds to the value of $\frac{c}{v+c}$ in step 3. Value = 2.75

Determine also value of w_m, and v_m corresponding to the value of $\frac{c}{v+c}$.

Values: $v_m = 0.290$ and $w_m = 0.250$.

5. The amount of coarse aggregate to use is arbitrarily chosen and for economic reasons is made as large as possible. For pebbles concrete the value of b, which is the proportion of coarse aggregate in the concrete, can be as large as 0.45 and for crushed stone concrete 0.40.

6. From the value of v_m found in step 4, compute the value of v. The proportion of mortar then in the concrete is 0.55 for pebbles concrete. If the value of v_m (proportion of voids in the mortar) is 0.29, then the value of v (proportion of voids in the concrete) wil be $0.55 \times 0.29 = 0.16$.

7. Solve for values of a and c. Since the volume of concrete is composed of the volumes of cement, fine aggregate, coarse aggregate, and voids, an equation can be written as follows: $a + b + c + v = 1$. Values for b and v are known, from which

$$a + c = 10.45 - 0.16 = 0.39$$

From step 4, a/c was found to be 2.75

$$a = 0.286$$
$$c = 0.104$$

8. The proportion by solid or absolute volumes is

$$0.104:0.286:0.450$$

9. Determine the weights per cubic foot and the ratios of solid to bulk volume for each material.

	Weight per Cubic Foot, Pounds	Ratio of Solid to Bulk Volume
Cement	94	0.50
Fine aggregate	112	0.60
Pebbles	102	0.65

10. Divide each value in the proportion of step 8 by the ratio of solid to bulk volume in step 9.

$$\frac{0.104}{0.5} = 0.208.$$
$$\frac{0.286}{0.6} = 0.477.$$
$$\frac{0.450}{0.65} = 0.692.$$

Values secured are quantities of materials necessary to produce a unit volume of concrete.

11. Figure proportion by bulk volume:

$$0.208:0.477:0.692$$
$$1:2.3:3.30$$

12. Compute the amount of mixing water necessary, by multiplying the value found in step 4 for w_m by (1-b).

$$\text{Value} = 0.55 \times 0.25 = 0.137$$

For every 0.208 cu. ft. of cement used, 0.137 cu. ft. of mixing water must be used. The water-cement ratio is $\frac{0.137}{0.208} = 0.66$.

Trial Method.—During the past several years there have been a number of contracts made in which the strength of the concrete was specified and the determination of the proportions of all the materials left to the contractor and engineer. Numerous other contracts have been made in which the water-cement ratio has been specified instead of the usual proportions of cement, fine and coarse aggregate. For given materials and conditions the strength of the concrete is a function of the water-cement ratio and the exact amounts of fine and coarse aggregate are immaterial so long as the concrete is workable. The amounts of fine and coarse aggregate should be fixed to produce a workable concrete, at the same time yielding as much concrete as possible. Since the determination of the proper workability is one of judgment, a method of proportioning known as the trial method is being developed. When strength alone is specified the determination of the proper water-cement ratio also becomes a part of the trial method.

Concrete may be considered as a combination of cement paste and aggregate, the strength of which is largely determined by the quality of the cement paste and the thoroughness of the bond between the paste and aggregate. Strength of the aggregate also affects the strength of the concrete, but since most aggregates are stronger than the cement paste the effect is negligible. Certain light-weight aggregates, however, are being used that are not as strong as the cement paste and do not produce, for the same quality of cement paste, concrete as strong as the regular stone and pebbles aggregates.

Since concrete is usually or can be thoroughly mixed, the quality of the cement paste is the only item that needs consideration here. As indicated elsewhere (Chap. 11) there are a number of factors affecting the quality of the cement paste such as: characteristics of the cement, richness of mix, age, curing conditions, and impurities in the aggregate which may reduce the strength. The problem is to find out what combination of materials will produce a given strength, at a certain age, and of a given consistency.

First the strength of concrete to be made must be chosen. Two thousand pound concrete is generally used for reinforced concrete of the usual design and 4,000-pound concrete for pavements. Next, the age at which this strength is to be attained must be selected. Present practice is to try to get desired

strengths at ages varying from 3 to 7 days. The choice of consistency depends upon working conditions, with pavement concrete normally of a drier consistency than that for reinforced concrete. Pavement concrete should have a consistency represented by a slump of 1 to 2 in. while reinforced concrete will normally need to have a slump of 4 to 6 in. Another factor which must be appraised is the temperature of the concrete during the curing period. From the curves in Chap. 11 fairly accurate estimates can be made of the strengths likely to be secured with standard portland cements at ages between 1 and 28 days for the usual range of water-cement ratios. Effect of temperature may be estimated from Fig. 93, values varying from 25 to 50 lb. per degree of temperature. Select a water-cement ratio which should give the desired strength. This value should be checked by actual tests using the materials to be used in construction and with the concrete made and cured as it will be on the job.

The next step is to determine the amounts of fine and coarse aggregates necessary to give the desired consistency. Fine aggregate is that portion of the aggregate passing through a ¼-in. square opening sieve and coarse aggregate is that portion retained. Prepare a cement paste with the water and cement in the proportions determined above. Then add aggregate until the desired consistency is obtained. Note how much fine and coarse aggregate is used. In working out this detail it is suggested that for the first trial the amount of coarse aggregate be one and one-fourth times the amount of fine aggregate, and that in subsequent trials the amount of coarse aggregate be increased one-fourth each time until it is twice as much as the fine. Note each time the consistency workability, and amount of concrete produced. Select the proportion which gives the proper workability. The amount of concrete produced will not vary a great deal between the 1½ and 2 ratios of coarse to fine.

The checking of the water-cement ratio selected may be combined with the determination of the proportions of aggregate, by making the concrete into cylinders and testing at the chosen ages. If the desired strengths are not secured, increase or decrease water cement ratio as necessary.

In Tables 8 and 10 are given some typical relations between cement content, water-cement ratio, consistency, and proportions

of aggregate, which were developed using average materials for some of the more common mixes. In Table 8, for instance, for a 1:2:3 mix, if 6 gal. of mixing water per sack of cement are used the consistency will be such that there probably will be a 1-in. slump, while if 8 gal. are used the slump may be around 8½ in. On the other hand 6 gal. of mixing water will not produce workable concrete for the 1:2½:4 and the 1:3:5 mixes. The table is presented merely to show what can be expected under average conditions.

TABLE 8.[1]—TYPICAL RELATIONS BETWEEN QUANTITY OF CEMENT, WATER-CEMENT RATIO, AND CONSISTENCY

		Slumps—inches				
Mix		1:1½:3	1:2:3	1:2:4	1:2½:4	1:3:5
Cement[2] content		6.4	5.8	5.2	4.75	4.0
Water mixing	6 gal.	7	1	0		
	7 gal.	8½	7	4	½	
	8 gal.	9	8½	7	4	0

[1] Compiled from a paper by McMILLAN and WALKER, "Use of Water-cement Specification on the Portland Cement Association Building," *Proc. Am. Concrete Inst.*, 1926.

[2] Bags per cubic yard of concrete.

Sand in this series of tests was graded 0-No. 4 sieve and the pebbles from No. 4 to 1½ in. F. M. = 3.14 and 7.00.

TABLE 9.[1]—TYPICAL RELATIONS BETWEEN PROPORTIONS OF FINE AGGREGATE, CONSISTENCY, AND CEMENT CONTENT

Mix		1:3:4	1:2½:4	1:2:4	1:1½:4
Cement content, bags per cubic yard		4.3	4.6	5.1	5.5
Mixing water	6 gal.			0	1½
	7 gal.		¼	4¼	6
	8 gal.	½	4	7	7½

[1] Compiled from a paper by McMILLAN and WALKER, "Use of Water-cement Specification on the Portland Cement Association Building," *Proc. Am. Concrete Inst.*, 1926.

Sand in this series of tests was graded 0-No. 4 and the pebbles from No. 4 to 1½ in. F. M. = 3.14 and 700.

TABLE 10.—TYPICAL RELATIONS BETWEEN PROPORTION OF COARSE AGGREGATE, CONSISTENCY, AND CEMENT CONTENT

Mix		1:2:0	1:2:1	1:2:2	1:2:3	1:2:4	1:2:5
Cement content, bags per cubic yard		10.1	8.2	6.8	5.8	5.1	4.5
Mixing water	6 gal.	9	8	4¾	1	0	
	7 gal.	11	10	9	7½	4¼	½
	8 gal.				8½	7	4½

[1] Compiled from a paper by McMILLAN and WALKER, "Use of Water-cement Specification on the Portland Cement Association Building," *Proc. Am. Concrete Inst.*, 1926.

Sand in this series of tests was graded 0-No. 4 sieve and the pebbles from No. 4 to 1½ in. F. M. = 3.14 and 7.00.

In Table 9, the proportion of coarse aggregate is kept constant and that of fine aggregate varied and in Table 10, the proportion of fine aggregate is kept constant and that of coarse aggregate varied. In the first case for any water-cement ratio, increasing the proportion of fine aggregate produces stiffer consistencies and with less cement content. According to the water-cement ratio strength law the same strength will be secured for any of these mixes using same water content. A 1:2:4 mix as often used on construction may be handled much easier by increasing the proportion of sand and without changing the amount of mixing water. The slump will be less but the mix with the greater amount of sand will be much more workable.

In Table 10 is indicated how the cement content and consistency change as the proportion of coarse aggregate is varied. For any water content, the addition of coarse aggregate stiffens the mix and if anything, will make the concrete less workable.

Questions

1. Give history of concrete proportioning.
2. The various theories of proportioning are based on tests made under what conditions? Are these conditions the same as those likely to be encountered in the field? Of what value are these theories in doing field work?
3. What is meant by empirical proportioning? What proportions are used for various classes of work?

4. Give purpose and scope of Fuller and Thompson's studies of proportioning.

5. Give purpose and scope of Abrams' studies. What is fineness modulus? water-cement ratio? What was the important result of Abrams' work?

6. Give purpose and scope of Edwards and Young's work.

7. Give purpose and scope of Talbot and Richart's studies. What is basic water content? relative water content? cement-space ratio?

8. What is the trial method of proportioning? What parts of the work of the various investigators is used in this method?

9. What changes in materials have taken place since these studies were made? How do the changes affect the problem of proportioning?

CHAPTER 7

MAKING OF CONCRETE

The production of concrete involves the operations of handling and measuring materials, mixing, transporting, placing, finishing, and curing. Any or all of these items may contribute to the success or failure of the work. In a general discussion of this kind it is not possible to say that if certain things are done or not done, the strength will be increased or decreased a certain amount. There are a number of items which affect the strength of concrete and in the field it is not possible to control all of these very carefully. If only one factor is varied we may estimate what the strength may be as the variations take place. It is much better to make test specimens and determine for the conditions on that particular job, just what variations in strengths are being secured. An attempt will be made in this and the next chapter to outline what is generally considered to be good practice.

Transportation and Storage of Materials

Materials for concrete must as a general rule be transported from the source of supply and stored until needed to make concrete. Occasionally a contractor will have a concrete-making plant at a gravel pit which will eliminate the necessity for any transportation of the aggregates.

Most contractors build up a reserve of both cement and aggregates before pouring of the concrete begins. This is desirable in that the contractor assures himself of continued production during the months when weather conditions are the most favorable and when he is ready to work. During the winter months it is not possible for the sand and gravel producers to operate, but they can begin before the time for construction to start. Storage of cement any length of time after making is not desirable inasmuch as the strength of the concrete made with it will not be as great as if made immediately following production.[1]

[1] Abrams, Duff A., "Effect of Storage of Cement," *Structural Materials Research Laboratory, Lewis Institute, Bull.* 6.

Storage has a greater effect on the early strengths than on the later ones as indicated in Fig. 52. Often a cement will be able to pass the A. S. T. M. minimum specifications even after a year's storage because the margin was large when the cement was new. A safe rule to follow is not to put in storage more cement than can be used in from 3 to 4 months after it is made.

The amount of materials put in reserve will depend somewhat upon the contractor's past experiences and his estimate of what

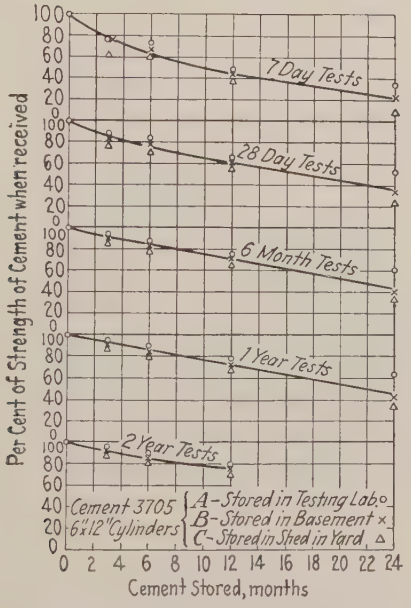


FIG. 52.—Effect of storage of cement on compressive strengths of 1:5 concrete. (*From "Effect of Storage of Cement," by Duff A. Abrams, Bull. 6, Structural Materials Research Laboratory.*)

conditions are likely to be during the construction season. The reserve should be at least large enough to tide over any periods when it will not be possible to get materials. In 1922, there was a general shortage of materials in the middle west with the result that for the next few years contractors put in extra large amounts. Materials conditions were much inproved by 1927 and the tendency was to place less material in storage.

When regular placing of concrete begins, daily shipments are started which will be sufficient to take care of each day's work. With everything running according to schedule, all of the

materials can be used each day without placing any in storage, an item of additional expense. It is, of course, not possible to operate upon an exact schedule, largely because of weather conditions, so that it is necessary to put materials in storage or draw upon the storage supply from time to time. Occasionally a contractor will try to operate without any reserve or without any facilities for handling reserve materials. The railroads make demurrage charges if the cars are not unloaded within a certain time, which is known as the free time and which is usually 2 days. The amount charged increases with the time the cars

FIG. 53.—A good type of metal portable cement shed.

remain loaded. Some railroads sign agreements with the contractors by which the contractor may offset some of the demurrage charges by unloading cars before the free time limit is up. Accounts are normally settled at the end of each month.

On some jobs prompt performance of the work is an important item and the engineer will require in the specifications that the contractor maintain a reserve supply so that work can always be done. This clause is necessary only when the producers are not meeting the demands during the construction season.

Cement.—Cement is usually shipped in box cars, either in bulk or in bags. When the supply of box cars is insufficient, gondola cars may be used, but this necessitates the use of a waterproof covering which may be a total loss to the manufacturer after it is used once. For jobs near a cement plant shipments are often made by truck. Shipments may also be made by boat. Horse and Buggy — A

Cement must be stored in a dry place. For the reserve supply it is advisable to use a building of some kind, generally of a temporary nature, which is normally built of wood and covered with tar paper. The floor level of the cement shed should be high enough so that the men in handling the cement can walk into the railroad car or on the truck without stepping up or down. The floor level should be high enough so that the cement will not become wet through the floor.

Small quantities of cement are frequently stored on construction work under a canvas. It is claimed by the manufacturers of the new multiple-wall paper bag that no covering is necessary for short periods of outside storage.

Aggregates.—Aggregates are shipped in gondola cars or trucked if the haul is short enough. If a crane is used to unload directly from the car, the ordinary gondola car without bottom or side dump doors is preferred. It is difficult to close up all the openings on the cars with the bottom or side dump doors so that there will be no leakage of the sand. In a case a contractor has an unloading trestle, special efforts are made to close up the openings so that sand as well as coarse aggregate may be shipped in the dumping gondola.

It is ordinarily necessary to keep a man in the gondola car when unloading with a clamshell. In order to save the time of this man some contractors receive their coarse aggregate in bottom dump cars which are unloaded into a pit under and to one side of the track. The clamshell can then pick the material out of the pit without the aid of an attendant.

Storage Piles.—No special difficulties are experienced in the storage of fine aggregate in stock piles. There is ordinarily sufficient moisture in the sand to prevent segregation. It is difficult, however, to prevent segregation of the coarse aggregate. Definite provisions are usually made in the specifications covering the method of building up storage piles of coarse aggregates. Stock piles should be built up in layers not exceeding 4 ft. in thickness. The first layer should extend over as much area as the stock pile is ever to cover. The second layer should cover the first layer entirely before the third layer is started. *Stock piles should not be built by pyramiding.* If each bucketful from the crane is dropped in the same place each time there is a concentration of dust in the center of the pile and a segregation of the sizes. The larger particles roll down the side of the pile

with the result that the smaller sizes are in the center of the pile and the larger ones at the edge.

Because of the difficulty of maintaining a constant gradation in the coarse aggregate, it is quite likely that engineers generally will require the separation of the coarse aggregate into two or three sizes at the pit or quarry, and shipped, handled, measured, and placed into the mixer as such. In 1927 one state highway department began the practice of separating the coarse aggregate into three sizes as indicated above.

Stock piles of different aggregates should be kept separate to avoid mixing. The same crane will handle both materials so that there is an advantage in having the stock piles close together. A separating wall is sometimes necessary.

Storage Bins.—Overhead storage bins are used in connection with the various measuring devices. The aggregates are placed in the storage bins directly from the cars or from the storage piles by means of the clamshell. From the storage bins the materials flow by gravity into the measuring equipment.

In some of the storage bins there is a tendency for dust and dirt to collect in the corners. When the bins are emptied all of this dust and dirt is placed into a few batches of concrete, a practice which is undesirable. The ideal type of bin for coarse aggregate would be one with a perforated bottom to permit the fine material to escape.

Measurement of Materials

Uniformity and exactness in the amount of materials entering into each batch of concrete are generally recognized as being of the utmost importance. Variations in the amount of any one of the materials will cause variations in the amount of concrete produced, its consistency, and strength, all of which may be undesirable. The engineer is interested primarily in securing uniform strength and the contractor in getting the proper amount of concrete. Variations in consistency increase the difficulty of securing uniformly smooth surfaces, something which is highly desirable in concrete pavements.

Size of Batch.—The size of a batch of concrete is usually indicated by the number of bags of cement in it and the proportions of the materials, as, a five-bag batch of 1:2:4 concrete. Mixers, however, are rated by the manufacturer according to the number of cubic feet of mixed concrete which can be produced

at one time. Table 11 gives the capacities of various mixers in terms of the number of bags of cement per batch for different mixes.

Measurement of Cement.—Most contractors buy cement in bags so that the problem of measuring cement is easily taken care of. A small percentage of cement is shipped in bulk, which necessitates the installation of weighing apparatus on the job. Measurement of bulk cement by volume is unsatisfactory. A cubic foot of cement may be made to weigh from about 60 to 125 lb. depending upon the amount of compaction. The selection of 94 lb. as the weight of 1 cu. ft. of cement is purely arbitrary. Since most of our knowledge of concrete is based on cement weighing 94 lb. per cubic foot, it is well to continue on that basis.

Some mixers are not large enough to accommodate a one-bag batch, which necessitates the splitting of a bag. On a job which does not warrant the use of a larger mixer, the use of weighing equipment for the cement is also unwarranted. Measurement by a shovel is undesirable, but oftentimes unavoidable on these small jobs.

In measuring cement with shovels it is well to empty a sack full into a box and determine the number of shovelsful per bag. The number of shovelsful per bag for each of the other materials should also be determined. The cement which is emptied out of the sack will not be so compact as it is in the box. Unless this fact is recognized in determining the number of shovelsful of each material per batch, the amount of cement used will fall short of that required.

Example.—A contractor has a small mixer which will accommodate a one-bag batch of 1:2:4 concrete. There is no skip on the mixer so that all the materials must be shoveled in. The contractor's men decide to empty the cement into a box and shovel it into the mixer. No attempt is made to place a bag of cement in the box each time and to empty the box before putting in any more cement. It is found there are 5 shovelsful of cement per bag, 4 shovelsful of sand and 4½ of pebbles. The amounts per batch would be 5 shovelsful of cement, 8 of sand, and 18 of pebbles. As usually done, however, the quantities used would be 5 of cement, 10 of sand, and 20 of pebbles. The strength of the concrete would be reduced while the amount of concrete produced would be increased per bag of cement.

It is difficult to get all of the cement out of a cloth sack and most workmen are inclined to leave a pound or two in each

bag. This is an item which may need watching, especially in case the contractor or dealer is recovering this cement for resale. The paper sack does not have this objectionable feature.

Measurement of Water.—All of the larger and better mixers are equipped with water tanks from which exact amounts of water may be taken automatically for each batch. These tanks as a rule are not graduated so that it is not possible to know the exact amount of water being used per batch without calibrating them. With the increased use of the water-cement specification, mixer manufacturers will make the graduated tanks.

On the small jobs usually not much attention is paid to the amount of mixing water. The dry materials are put into the drum and the desired consistency secured by adding water. The better method is to determine the amount of mixing water necessary to produce concrete of the desired consistency and then place that amount of water with the cement into the mixer first. The desired consistency can then be secured by adding aggregate. This practice will result in more uniform concrete and in the use of stiffer consistencies. Once the contractor sees that he can secure more concrete with the same amount of cement by using stiffer consistencies, he will use them. No decrease in strength should result. Water on these small jobs is usually measured in a bucket if it is measured at all.

Careful control of the quantities of water and cement are important inasmuch as they constitute the cement paste which is the binding material. Other things may affect the strength of the cement paste, but these other things would be the same regardless of the amounts of water and cement used.

Measurement of Aggregates.—Aggregates are now generally divided into two sizes, known as fine and coarse aggregate. Specifications provide that these materials shall be measured separately. In case the coarse aggregate is divided into two or three sizes, it is necessary to have a greater number of devices for measuring the coarse aggregate.

Measurement by shovelsful or by the wheelbarrow is not accurate and should be allowed only on relatively unimportant work. On the small jobs where accurate measuring equipment is not warranted, more attention should be paid to the water and the cement than to the aggregates. On larger and more important work all of the materials should be carefully measured either by weight or by volume.

Fine Aggregate.—Sand is most commonly used as fine aggregate. It contains moisture which increases its bulk volume.

FIG. 54.—Mixing plant of a paving contractor. Mixed concrete is also sold by the ton.

FIG. 55.—Weighing apparatus for aggregates as used on a highway construction job.

Moisture contents vary from about 2 to 10 per cent, with most values between 4 and 6 per cent. The amount of bulking for any given percentage of moisture varies with the gradation of

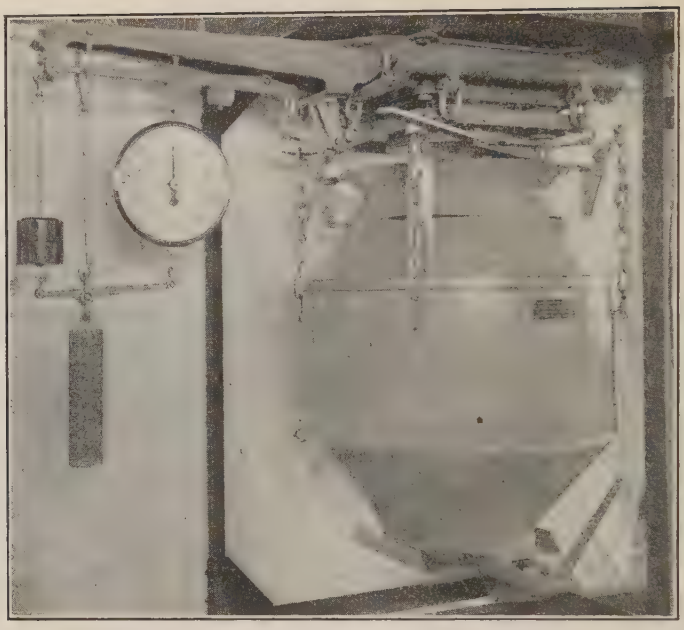


FIG. 56*a*.—Johnson measuring hopper.

This piece of equipment is adjustable as to quantity measured and may be furnished with or without the weighing device.

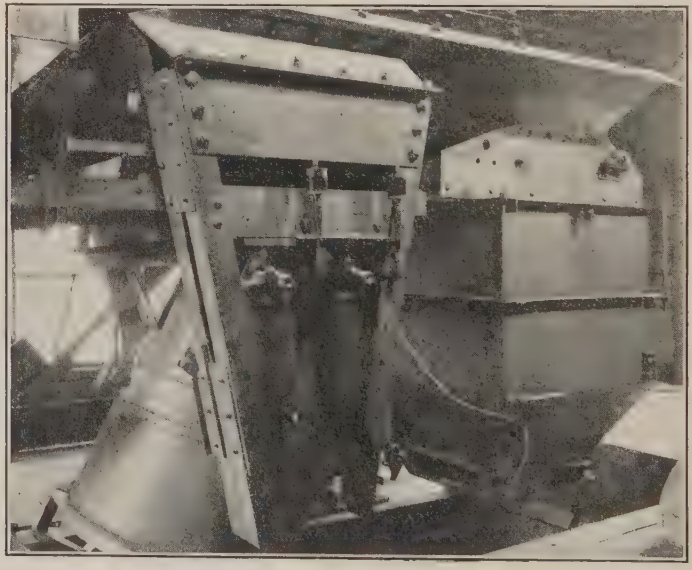


FIG. 56*b*.—Inundator at the left is just swinging into upright position after discharging.

the aggregate and the surface condition of the particles. It is not uncommon to find sand bulked as much as 20 per cent due to the moisture content.[1]

Specifications are usually written calling for the aggregates to be measured based on a dry and loose condition. If the sand contains moisture causing a change in the bulk volume, due allowance for that bulking should be made so that the amount of solids will be the same in either case (see chapter on estimating for method of computing correction).

It has been observed that uniform amounts of a given sand may be secured if measured volumetrically under water. One manufacturing concern has put this fact to a practical use and is making a measuring apparatus known as the *inundator*, which measures the sand by volume under water. The apparatus consists of a hollow cylinder pivoted on the sides so that it may be easily dumped and returned to the upright position. It is made with an adjustable bottom to accommodate various amounts of aggregate. Sufficient water is placed in the cylinder so that when the sand is all in, the level of the water is the same as that of the sand. An excess of water is actually placed in the cylinder and allowed to overflow as the sand fills the cylinder. The inundated volume of sand is about equal to the loose dry volume or a little less. The inundated volume is a more definite quantity than is the loose dry volume. In the writing of specifications the basis of measurement of the aggregates should be clearly given.

There are several types of devices on the market for measuring aggregate by bulk volume. The chief requirements are ease of operation, certainty of emptying and filling each time, and accuracy. With this type of apparatus a correction should be made in the volume of the moist sand as measured in order to compensate for the bulking action, as previously mentioned. Moisture contents and percentages of bulking remain fairly constant for a sand from any given pit. Once the correction is made, not much further attention is needed.

[1] As a result of their investigations on bulking of sand, the Illinois Division of Highways during the construction season of 1927 permitted their contractors to increase the bulk volume of the sand as measured on the job a uniform amount of 15 per cent. The Illinois mix is 1:2:3½. For a six-bag batch the contractor would measure out 13.8 instead of the usual 12 cu. ft.

Measurement of aggregates by weighing has been successfully tried but has not become very general. This is probably due to the feeling that a weighing apparatus can be easily gotten out of adjustment. If no attention is paid to the moisture, there will be less error in weighed aggregates than in those measured by volume. Five per cent of moisture may cause 20 per cent bulking, in which case volumetric measurements are in error four times as much as the weighed aggregates.

FIG. 57.—Proportioning plant of a paving contractor.

In order to determine the proper weights of materials per batch it is necessary to know the relationship between weight and volume, since practically all specifications are written for the materials to be measured on a volume basis. First the weight per cubic foot of the materials must be determined on the loose dry condition as usually given in the specifications. Then the percentage of moisture based on the dry weight of the sand must also be determined. The weight of the moist sand or coarse aggregate is equal to the weight of the materials dry plus the weight of the contained moisture. Weighing a cubic foot of the moist material will give a different result.

Coarse Aggregate.—Much of the discussion under fine aggregate is also applicable to coarse aggregate. Coarse aggregates are not bulked to any appreciable extent due to contained moisture so that volumetric measurement has generally been considered satisfactory.

Since the volume of mortar in the concrete is more than enough to fill the voids in the coarse aggregate, the latter may be considered as a filler for the former, increasing its volume an amount equal to the solid volume of the coarse aggregate. If the coarse aggregate is measured by bulk volume, the only way the solid

FIG. 58.—Charging skip on paving mixer. Batch boxes on industrial railroad cars are used in this case to bring the proportioned batches to the mixer.

volume can vary from batch to batch is for the gradation to vary. This is possible as indicated in the discussion on storage of materials. If the coarse aggregate is weighed, uniform amounts by solid volume may be secured, in which case it is necessary to take into account the contained moisture.

MIXING

Mixing is the operation of incorporating the cement paste in the mineral aggregate. As actually performed the cement paste is itself produced at the same time. All of the materials, cement, water, and aggregates, are placed in the mixer at the same time and mixing is continued until the cement and water are thoroughly mixed together into a paste, which in turn must be distributed through the aggregate.

At first all concrete was mixed by hand but today this method is impractical on all except the very small and unimportant jobs. Machine mixing is faster, cheaper, and produces better concrete.

Mixers.—The batch mixer is universally used at the present time. A batch mixer is one in which all the materials for one batch are placed in the drum, mixed and discharged before any more materials are added. Some of the first mixers operated continuously, which accounts for the designation batch mixer. The old continuous mixer did not produce concrete of uniform quality and was therefore abandoned.

The mixing chamber of all mixers is known as a drum. Paddles are usually placed in the drum to aid in the mixing operation.

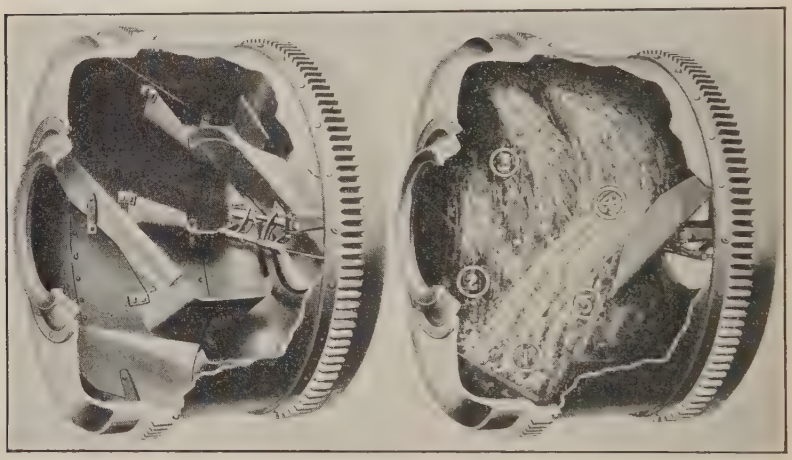


FIG. 59.—Interior views of drum of concrete mixer.

The paddles also work the concrete towards the discharge end and thus aid in emptying the drum which is accomplished by inserting a chute into the drum. Some of the small mixers have drums which may be tilted to discharge the concrete. The tilting drum type is much easier to clean in the smaller sizes.

Mixers are charged in one of three ways: with a skip, from a special storage hopper, or by direct shoveling into the drum. Only small mixers on unimportant work should be loaded by the last method. Stationary mixers usually use the second method, while the non-stationary ones use the first method. The skip receives the materials from the ground level and then elevates them so that they will flow by gravity into the drum. For

stationary mixers it is cheaper to elevate the materials a little higher with a clamshell so that a small special hopper may be placed between the measuring apparatus and the mixer. In

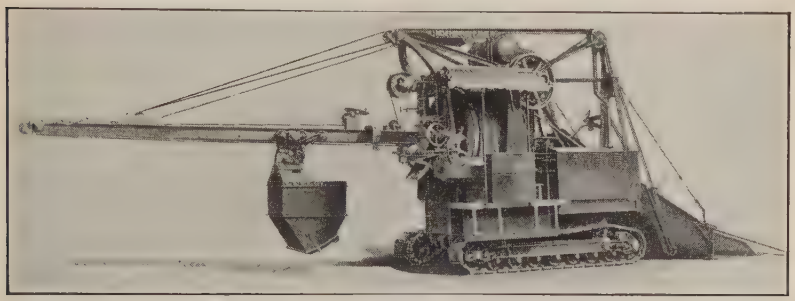


FIG. 60.—A type of traveling mixer used largely on paving work. The cement and aggregates are dumped in the skip at the right and the mixed concrete is spread on the subgrade with the bucket operating on the boom at the left.

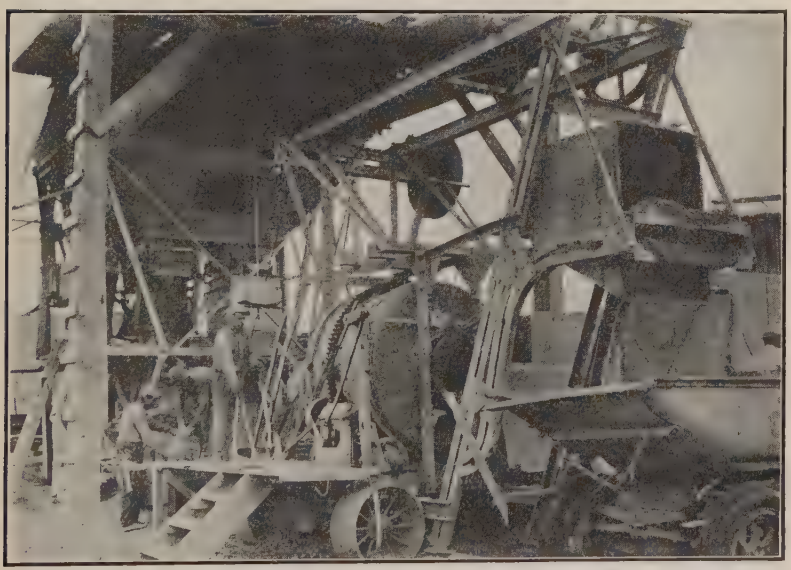


FIG. 61.—Central mixing plant. Note inundator in the background and the method of loading trucks with the mixed concrete. This arrangement permits the mixer to operate more regularly than is normally the case and with fewer trucks.

some cases the material is run directly from the measuring hoppers into the mixer.

Mixers are run by gasoline, electric or steam power. Electric power where available is usually used for stationary mixers and

gasoline for the movable ones. Steam is available for either type but is rapidly decreasing in use.

Time of Mixing.—The average mixer is designed so that the concrete is satisfactorily mixed in from 1 to 1½ min., and practice today is to require at least a full minute of mixing after all the materials are in the drum and before any of the concrete is discharged. It is generally considered that not

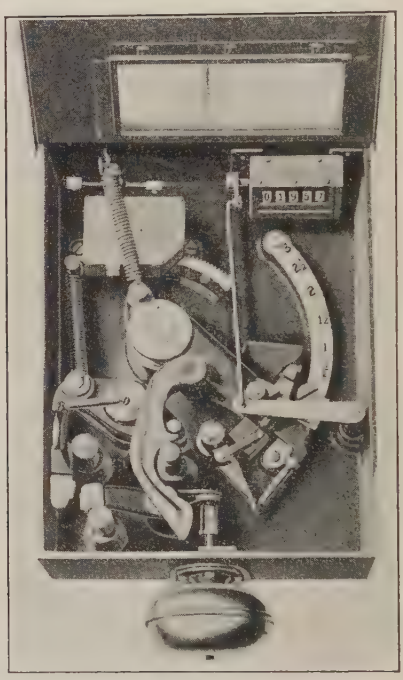


FIG. 62.—Timing device attached to mixers to control the length of mixing time.

enough additional strength is gained by increasing the time of mixing above 2 min. to warrant doing so.

Most mixers are designed for the drum to operate at a speed of 18 to 20 r.p.m. Increasing or decreasing the rate excessively above or below the rate specified by the manufacturer is likely to affect the thoroughness of mixing. Mixers should operate at the speed designated by the manufacturer as best.

In order to guarantee the proper amount of mixing some engineers require a timing device to be placed on the mixer, which will start measuring time as the materials go into the drum and which will lock the discharge apparatus until the full

amount of mixing is completed. A bell is usually rung to indicate when the time is up. Timing devices take the guess work out of the mixing operation and should be on every mixer doing work on important jobs.

Hand Mixing.—At one time people generally felt that hand mixing was superior to machine mixing but the mixers have so much in their favor now that in most cases hand mixing of con-

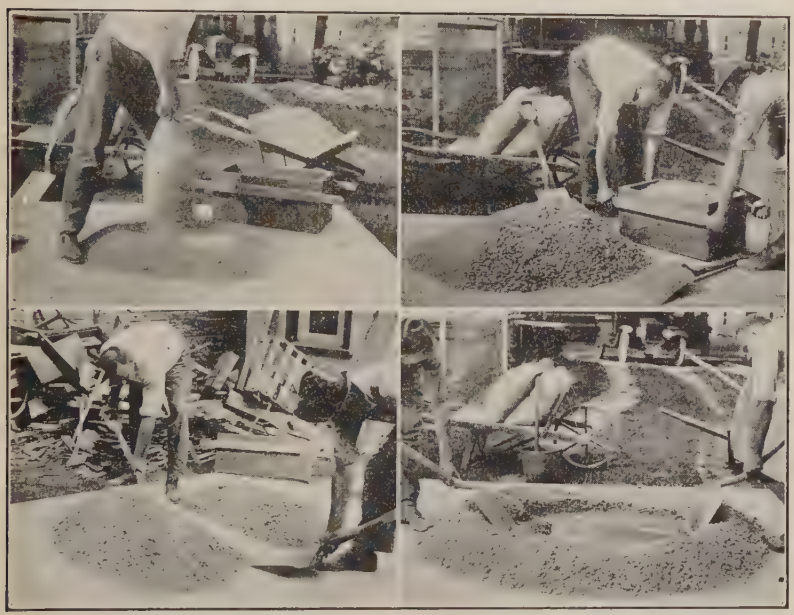


FIG. 63.—Steps in the mixing of concrete by hand.

crete is not permitted. Hand mixing occasionally is necessary and the accompanying pictures (Fig. 63) are included to show how the operations are carried out. After the materials are carefully measured, the cement and sand should be mixed first dry. Then the coarse aggregate should be spread over the cement-sand mixture and the whole remixed again. Form a crater in the center into which the mixing water may be poured. As soon as the water is all taken up, the mixing may proceed.

TABLE 11.—CAPACITIES OF STANDARD MIXERS[1]

Proportions	Size of batch in bags of cement									
	Construction mixers							Road mixers		
	3½-S	5-S	7-S	10-S	14-S	21-S	28-S	10-E	13-E	27-E
1:1½:3	1	1	2	3	4	6	8	2	4	7
1:1½:3½	½	1	1	2	3	5	7	2	3	7
1:2:3	½	1	1	2	3	5	7	2	3	7
1:1¾:3½	½	1	1	2	3	5	7	2	3	6
1:2:3½	½	1	1	2	3	5	7	2	3	6
1:2:4	½	1	1	2	3	4	6	2	3	6
1:2½:4	½	1	1	2	3	4	6	2	3	5
1:2:5	½	½	1	2	2	4	6	1	2	5
1:2½:5	½	½	1	1	2	4	5	1	2	5
1:3:5	½	½	1	1	2	3	5	1	2	4
1:3:6	½	½	1	1	2	3	4	1	2	4

[1] As specified by the Associated General Contractors' Association. Other sizes are made special.

Questions

1. What effect does length of storage have on the quality of cement? Can cement be used too soon after it is manufactured? Why? How can this difficulty be overcome?

2. Why is it necessary in the handling of aggregates to maintain uniformity in the gradation from batch to batch? Where is difficulty likely to be experienced?

3. How is cement measured? How are the aggregates measured? How is the water measured?

4. What effect does moisture have on the bulk volume of fine granular materials? How does this affect the problem of measuring concrete aggregates on construction work? How is the difficulty overcome?

5. Discuss relative merits of weighing and measuring aggregates by bulk volume. Disregarding moisture content entirely, which method gives the greater accuracy?

6. What is the inundator? What are its merits? How does the inundated volume compare with the loose dry volume?

7. What effects does time of mixing have upon the strength of concrete? upon its workability? What is the usual mixing time specified? How is it controlled on the job?

8. Describe proper methods to follow in hand mixing.

CHAPTER 8

PLACING, FINISHING, AND CURING OF CONCRETE

Distribution and Placing

Distribution and placing of the concrete involves its movement from the mixer to the final place in the finished structure. Methods and time involved may affect the strength and quality of the concrete. Conditions on various jobs are different and the proper method to use must be determined for each one.

Time Limit.—Most engineers require that concrete must be placed in the forms within from 30 to 45 min. after it is mixed. In setting an arbitrary limit, such as 45 min., several factors which bear on the question are neglected. It is considered desirable to have the concrete in its final place before the cement has taken its initial set. Temperature affects the rate of setting. Time of setting is determined at 70°F. Temperatures above 70°F. hasten the setting while temperatures below 70°F. retard the setting. In hot weather the time limit should be shorter than that set for colder weather.

The other factor neglected is the time of setting of the cement itself. At 70°F. all cements are required not to have taken their initial set within 1 hour as measured with the Gillmore needles or 45 min. with the Vicat apparatus. Some cements have times of initial set as much as 3 hours.

A safe limit to use under ordinary circumstances is probably 30 min.; 45 min. is probably also safe but has the factor of safety reduced somewhat. Even with an interval of several hours between mixing and placing, the concrete would not be ruined so far as gaining strength is concerned. The amount of strength gained would not be as large as when placed immediately.

The general feeling amongst engineers has been that concrete can not be retempered, that is remixed with or without additional water after initial set has taken place, without seriously reducing the strength. The above recommendations are based on that feeling. Occasional tests recently have indicated this idea is

incorrect and that remixing without addition of water after an hour or two adds strength. More test data must be available before many engineers will change their ideas on this point.

The engineer should indicate in the specifications as nearly as possible the limits which are to be imposed during construction. In case it is necessary to observe these rules it will be necessary to secure a record of the time each batch was mixed. The practice has been to throw away batches which are not placed within the time limit.

Fig. 64.—A concrete house. All walls, floors, partitions, roof, gutters and down spouts are poured monolithic reinforced concrete. Excepting the door and window frames and wooden trim, nothing used in the entire construction is inflammable. Note the architectural features in the poured concrete.

Methods of Distribution and Placing.—The methods of distributing and placing on any job will depend upon the existing conditions. Only general situations can be discussed here.

Paving Mixer on Subgrade.—The simplest operation of distribution and placing occurs when a paving mixer is moving along on the subgrade. The concrete is emptied first into a bucket operating on a boom on the mixer. From the bucket it is dumped into place in the pavement. Workmen with shovels spread it around approximately to the proper grade. On

country road work mechanical finishing machines are sometimes used. Methods of finishing are discussed further on in this chapter.

The cost of distribution in this case is low but is counterbalanced by a high cost of getting the materials into the mixer.

Central Mixing Plants.—On many highway jobs and on some building construction, the concrete is mixed at a central mixing plant located at the railroad siding or the gravel pit. Movement

FIG. 65.—Handling concrete with a bucket conveyor which can be moved about as desired.

of the mixed concrete is usually done with automobile trucks. Occasionally industrial railroad equipment is used. The trucks have a capacity of from ½ to 2 cu. yd. and the truck of about 1 cu. yd. capacity is most common. Some contractors prefer light trucks carrying small loads while others prefer the larger types of greater carrying capacity.

Trucks for hauling wet mix concrete should be designed to dump upon the release of a catch by the driver. Frequently some of the concrete will remain in the truck and unless the

body is held in the dumping position will return to the normal loaded position. It is only with difficulty that the body can be gotten to the dumping position again.

Whenever *wet mix* or central mixed concrete is used on building construction a receiving hopper must be provided into which the concrete may be dumped from the trucks. This hopper

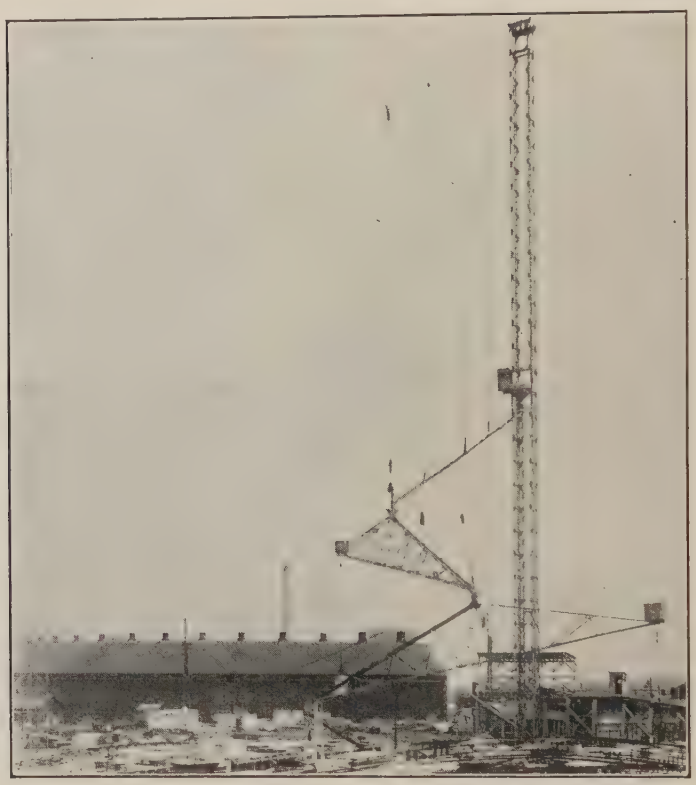


FIG. 66.—View showing a 240-ft. tower and chutes for distribution of concrete.

should be so designed and placed as to permit a minimum of hand handling of the concrete.

On construction jobs that cover a larger area, it is possible to use narrow or standard gage railroad equipment. The concrete can be mixed at a convenient point nearby and transported in containers on the railroad cars.

Methods of distribution at the building site will vary considerably and will depend somewhat upon the personal preferences

of the men in charge. The various methods may be listed as follows:

1. Chuting.
2. Buggies or wheelbarrows.
3. Overhead cableway.
4. Belt conveyor.

Chuting.—In this method the concrete is elevated so that it will flow by gravity down chutes into place in the forms. It has generally been considered necessary to use rather wet consistencies when the chuting method was employed, but on more recent jobs drier consistencies have been successfully used. When arbitrary proportions based on dry materials are specified and no allowance is made for bulking of the sand, the concrete may not contain sufficient fine aggregate to permit chuting of the drier consistencies. Correction for bulking will help and if not sufficient the proportions should be changed so that the amount of fine aggregate is increased. Concrete with as low as a 2-in. slump may be chuted if the gradation of the aggregate is correct.

Most of the chuting work has been done where the proportions were arbitrarily specified and based on dry volumes and it has been the general practice to use wet consistencies, which have caused segregation and weak concrete. When chuting is to be permitted the specifications should outline a method of supervision which will secure uniform concrete of the strength desired.

Concrete Buggies or Wheelbarrows.—Another method of distribution is to raise the concrete sufficiently (usually in an elevator) so as to discharge into a hopper from which it may be taken by gravity into concrete buggies or wheelbarrows to be moved (horizontally only) to the forms. This method of distribution is applicable to the smaller bridge jobs and to buildings and sidewalks. It permits the use of stiffer mixes than in the chuting method. Not as much money is spent in elevating the concrete but more is consumed in lateral distribution. A contractor working under a strength specification, can as pointed out above, increase the yield of the concrete by the use of the drier mixes.

Overhead Cableway.—Concrete construction jobs covering large areas or of great length are especially adapted to the use of an overhead cableway for the distribution of the concrete. Long bridges and dams, sewage-treatment and water-storage

FIG. 67.—Slack line overhead cableway used for excavation first and then for the placing of concrete.

FIG. 68.—Overhead cableway used in the construction of the Superior-Detroit high level bridge at Cleveland, Ohio.

basins come in the above classifications. In the case of the bridge or dam, the ends of the cable may be stationary, while in the others it has been found convenient to fasten the cable to towers that operate on extra-wide gage railroad track. A large bucket for transporting the concrete is operated back and forth on this cable. In the case of the North Side sewage treatment plant in Chicago, these buckets were filled with concrete at the mixers, transported on small railroad cars to the cableway, where they were picked up and moved to a receiving hopper. It is necessary to have a receiving hopper between the cableway

FIG. 69.—Belt conveyors are being used to advantage now to transport concrete from the mixer to the forms. Note the slope of the belt.

bucket and the forms; otherwise the force of the falling concrete might wreck the forms. The overhead cableway has proved satisfactory on a number of jobs because it has been available to move materials and equipment quickly and easily.

Belt Conveyer.—A recent development in methods of distribution is the belt conveyor, which moves the concrete both horizontally and vertically. Concrete of any consistency necessary in reinforced concrete work can be moved on the belt which may be run at an angle of 45 deg. or less with the horizontal.

Placing Concrete under Water.—It is frequently necessary to place concrete under water. This can be done without a great deal of extra effort and without injury to the concrete.

Portland cement will set and gain strength under water so that the only unusual problem is to get the concrete in place without washing the cement away from the aggregates. Concrete should not be allowed to drop unprotected through water. The best method of depositing concrete under water is with the *tremie* pipe. The tremie pipe may be from 6 to 14 in. in diameter

FIG. 70.—Mixing and placing plant for underwater concreting operations. A 1-yard mixer was mounted on the barge with an overhead bin, the mixer discharging directly into the bucket of the steel tower. A boom was mounted on the tower supporting a feed chute from the tower and also supporting a tremie chute with feed hopper. The end of the chute from the tower discharged directly into the tremie chute when it was lowered into the water, and the feed chute was made adjustable so it could be moved forward and backward as the position of the tremie chute changed. Tackle was arranged on the boom for raising and lowering the tremie chute.

and must be long enough to reach from the surface of the water down to the concrete. The pipe is first filled with concrete and lowered into the water until it reaches the bottom. Then as more concrete is added at the top, some is permitted to flow out at the bottom. Once the flow of concrete is started the bottom of the pipe is kept below the surface of the soft concrete. With this method there is practically no washing out of the cement. The pour should be continuous until the concrete is above the

surface of the water. Otherwise, there may be a porous seam where two different pourings join.

Another method of placing concrete is to use buckets to take it from the surface to its position under water. Some washing out of the cement takes place as the concrete is dumped from the bucket.

Finishing

Concrete surfaces may be finished in any one of the following methods: shovel, wooden float, canvas belt, steel trowel, spading tool, or grinding stone. The finish given will depend largely upon the use to be made of the surface.

The finish produced by going over the surface of the concrete with the back of a shovel is known as a *shovel finish.* Shovel finishes are sometimes given to pavement bases for bituminous wearing surfaces or to surfaces which are later to be covered with a portland cement mortar coating. Shovel finishes are not very smooth or attractive and are not recommended as good practice.

A *float finish* is secured by going over the surface with a wooden float. Wooden floats are of two types: hand and long handle. Hand floats are used where a reasonably smooth surface is desired, such as on a sidewalk. The long-handled float is used on larger surfaces where a bridge would be necessary in order to use the hand float. The long-handled float does not produce as smooth a surface as the hand float.

Canvas belts may be used to give about the same kind of a finish as the wooden float. The advantage of the canvas belt over the float is that the labor costs are much less. The canvas belt may be used on sidewalks or pavements.

A *steel trowel* produces a much smoother surface than does any of the other tools mentioned. It works better on mortars than on concrete. The steel trowel may be used to finish floors, steps, sidewalks, or any horizontal surface. Sidewalks, however, had better be finished with the float because the steel-trowel finish when wet is dangerously slippery.

Vertical surfaces are usually finished by *spading* the concrete as it is placed in the forms. The purpose of spading is to bring mortar to the surface against the form and to compact the concrete.

FIG. 71.—Showing steps in the construction of two-course combined curb and gutter.

a. The forms and strike-off tool.
b. Filling curb forms. Note that lower portion has been filled with concrete and that the inside curb form is held in place with clamps.
c. As soon as concrete is in place, the top coat of mortar is put on. The strike-off tool shapes the surface of the mortar.
d. Smoothing up irregularities with special curb tool. The ridge will be removed with an ordinary trowel.
e. Running edger.
f. Finished curb and gutter.

FIG. 72.—Showing segregation in poured concrete wall due to wet concrete, lack of spading, and flowing of concrete in forms.

Where an unusually smooth surface is desired the concrete may be finished with a *grinding stone.* In such cases it is not uncommon to use special aggregates near the surface in order to produce certain color effects or designs. The grinding is continued until the cross-section of the aggregate is shown. Floors and walls of buildings are frequently finished in this manner. Sometimes the surface is smoothed up with a carborundum stone after the forms are removed.

Any surfaces of concrete exposed to the elements should be dense to prevent water from seeping in. Continued wetting and drying or freezing and thawing will in time disintegrate the surface unless the concrete is made strong enough to withstand such actions. Special effort should be made on exposed surfaces to secure dense, durable concrete in order to withstand this extra stain.

Ornamental Finishes.—Concrete is normally thought of as a material which lacks possibilities for ornamentation purposes. John Early of Washington, D. C., has been doing some very fine work with an exposed aggregate concrete. Architects are using portland cement stucco to secure desired color effects and designs on exterior walls. In other cases they are using the polished surfaces mentioned above. Designs are also being painted on the concrete. Brief descriptions will be given of each.

Work of Mr. Early.—Mr. Early is an artist and a sculptor, and plans all of the designs himself in consultation with the architects. Drawings are made full scale showing the arrangement of colors. From these drawings workmen trace the designs on a plaster-of-Paris board with a small gouging tool. Another plaster-of-Paris board is then cast over the first one so that the lines are raised rather than depressed. The concrete is poured on this second board.

Ordinary gray cement and specially prepared colored aggregates are used in the concrete which forms the surface layer. The aggregates may be either crushed marbles, colored vitrified shales, or colored glass. The surface layer of concrete with the special aggregates is placed on the plaster-of-Paris board and is then backed up with concrete using ordinary aggregates. Within 24 to 48 hours the form is removed and the aggregate exposed by means of wire brushes. All this work is done in the laboratory or workshop and when properly hardened is transported to the job and put in place. The Shrine of the Sacred

Heart in Washington, D. C., is probably Mr. Early's most notable piece of work.

Art Marbles.—Imitation marbles are being produced using colored cements and crushed marbles for the aggregate. In some cases no effort is made to imitate marble but certain patterns or designs are worked out through the use of colored cements and marble aggregates. In either case the methods are alike.

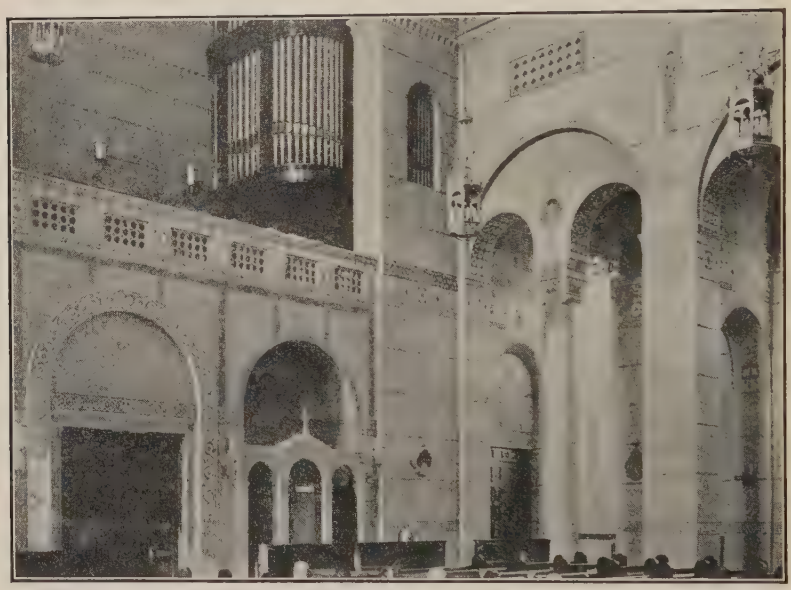


FIG. 73.—Interior view of Sacred Heart Church, Washington, D. C. Decorative effect secured through the use of colored aggregates in the surface layer of concrete.

Concrete made with cements and aggregates of the desired colors are molded into the required shapes. Normally only the surface layer about ½ in. in thickness is made with the special materials. Cheaper materials are used for the backing-up concrete. After the concrete has hardened properly the surface is ground away until the aggregate is exposed in cross section. Almost any color, combination of colors, or shape can be secured. The cost compares favorably with that of marble. This work is all done in the factory and the finished pieces are put in place as needed on the job.

Terrazzo.—Terrazzo is a form of art marble but is made in place in the structure. It is used mostly for floors in homes and public buildings of all kinds. The concrete is placed first in the usual manner. Colored aggregates are then spread over the surface and rolled in. As soon as the concrete has hardened sufficiently the surface is ground to expose the aggregates. Designs can be worked in or not as desired.

Cast Stone.—Exterior walls of buildings are being built with blocks of concrete which resemble cut natural stone. These are made of the same quality of concrete all the way through. Wetter mixes are used than in the case of the concrete

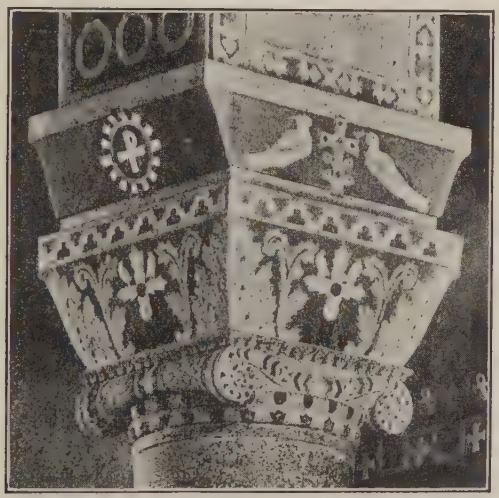
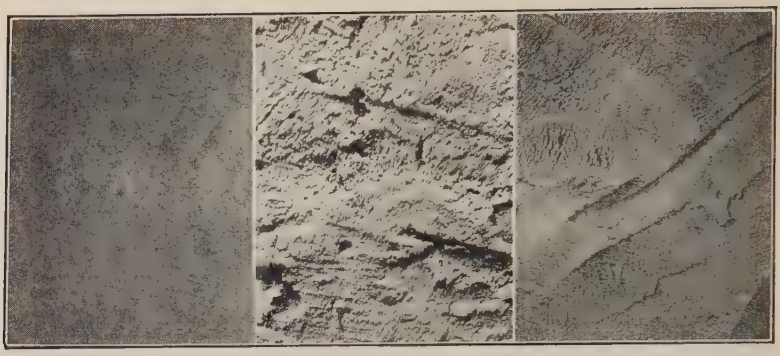


FIG. 74.—Showing detail of a column in the Sacred Heart Church, Washington, D. C.

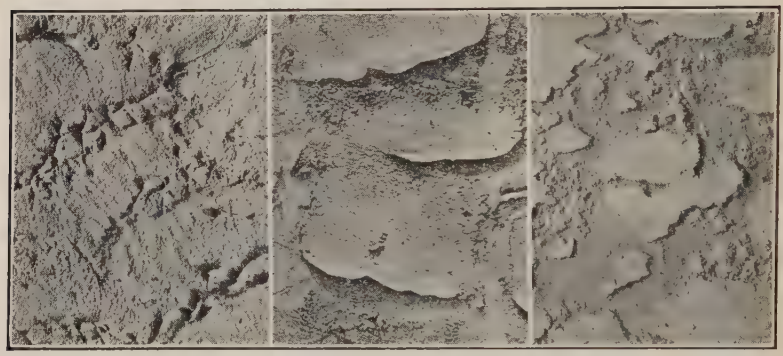
building blocks mentioned previously. The concrete is permitted to remain in the molds at least 24 hours. The block manufacturer has a secret method of securing the surface which resembles the cut stone.

Stucco.—Portland cement stuccoes are being used on the exteriors of homes and public buildings. Certain color effects and designs may be secured by the inclusion of a coloring compound or by the use of colored aggregates after the stucco is in place but before it has hardened. Rough or smooth finishes may be produced by the man doing the work. Certain designs or patterns may be worked in by shaping the stucco. A dash coat of colored stucco is extensively used on the Pacific coast



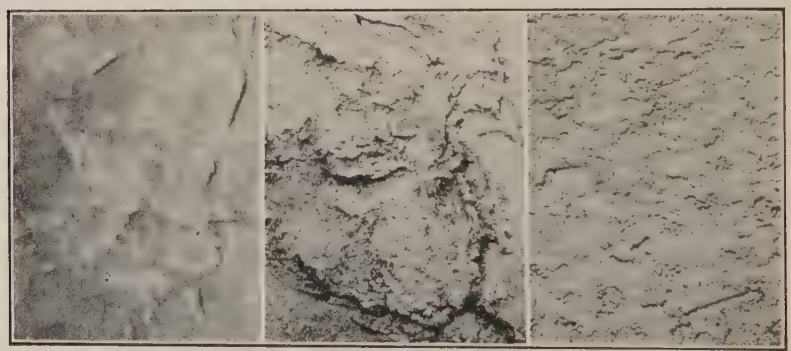
a. *b.* *c.*

a. Colonial. Sanded surface finished with wood or cork float.
b. California texture. A carpet floated rough cast.
c. French trowel. Finished with a sweep stroke of the trowel.



d *e* *f*

d. Italian Cottage. A sponge finish on a soft plastic surface.
e. English. Spotted by side stroke of trowel.
f. Italian. A troweled rough cast.



g *h* *i*

g. French Brush. Uneven sand surface, hand rubbed.
h. Spanish. Feathered with wood float.
i. English Cottage. Feathered with edge of trowel.

FIG. 75.—Some stucco finishes.

on monolithic walls to control color without changing the texture of the concrete.

Painted Decorations.—A great variety of decorative effects may be secured by staining and painting concrete surfaces. The final effect secured will depend somewhat upon the texture and freedom from blemishes of the surface. Special care must,

Fig. 76.—Painted decoration of ceiling in Los Angeles Public Library. Paint and stain were applied directly to the concrete.

therefore, be exercised and only experienced workmen employed when the best results are desired.

After the concrete has had a sufficient amount of moist curing, it should be thoroughly dried out before proceeding with the decorating work. A coat of aqueous solution of zinc sulphate (4 lb. of crystallized zinc sulphate to 1 gal. of water) should be applied first in order to neutralize any lime that may be on

the surface. By tinting the solution with a pigment color the danger of leaving untreated areas may be avoided.

After an interval of at least 48 hours, a primer coat of boiled linseed oil should be applied to prevent the stain or paint from penetrating too deeply in the concrete. Pigment color should also be added to the priming coat for the same reason as given above. If the concrete is dense it may be necessary to add turpentine to the oil in order to secure the desired penetration.

As soon as the priming coat is dry the surface is ready for the stain or paint. Stains consisting of a mixture of boiled linseed

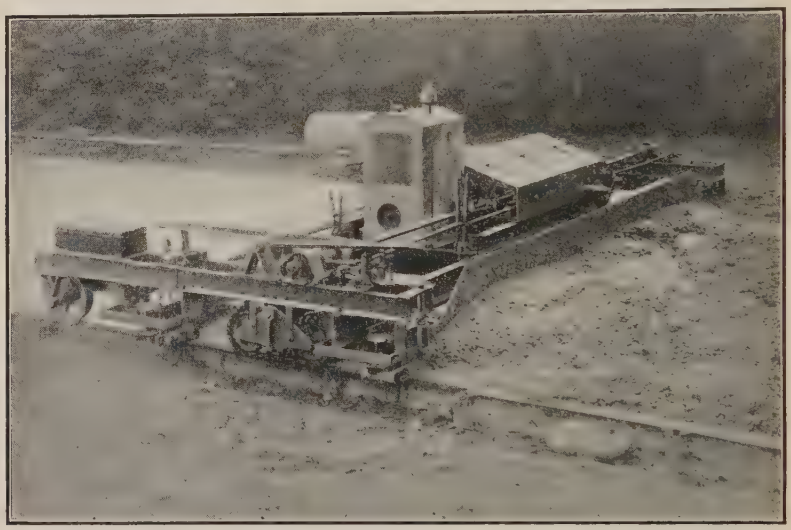


FIG. 77.—Screed type of finishing machine. There is no tamping bar on this machine.

oil and Chinawood oils, thinned with turpentine or naphtha and colored with pigments have proved satisfactory. A high-grade linseed oil paint can be used as a stain if thinned sufficiently. Pleasing effects have been secured by staining the entire surface and then stenciling designs on with paint. Thin clear varnish or shellacs may be applied to protect the painted surfaces.[1]

Finishing Concrete Pavements.—There are a variety of methods and combinations for finishing concrete pavements. First the concrete must be struck off to the desired shape and grade. The only method to secure a satisfactory surface is to

[1] For a more complete description see "Concrete in Architecture," a rochure prepared by the *Portland Cement Association.*

use a strikeoff which operates on side forms. Long-handled floats or lutes have proved unsatisfactory. After the concrete has been struck off to its proper shape, it is customary to roll or

FIG. 78.—Tamping type of finishing machine. Tamper is just back of screed.

tamp. Rolling and tamping should be kept at a minimum in order not to bring to the surface any dirt or laitance. Some engineers are omitting this step entirely. Solid and perforated

FIG. 79.—Checking surface with straight edge. Concrete pavements are required to be within ¼ in. of true.

rollers are available for rolling and mechanical tamping machines can be used on the country road for that operation. The rollers are pulled back and forth across the surface with ropes. The

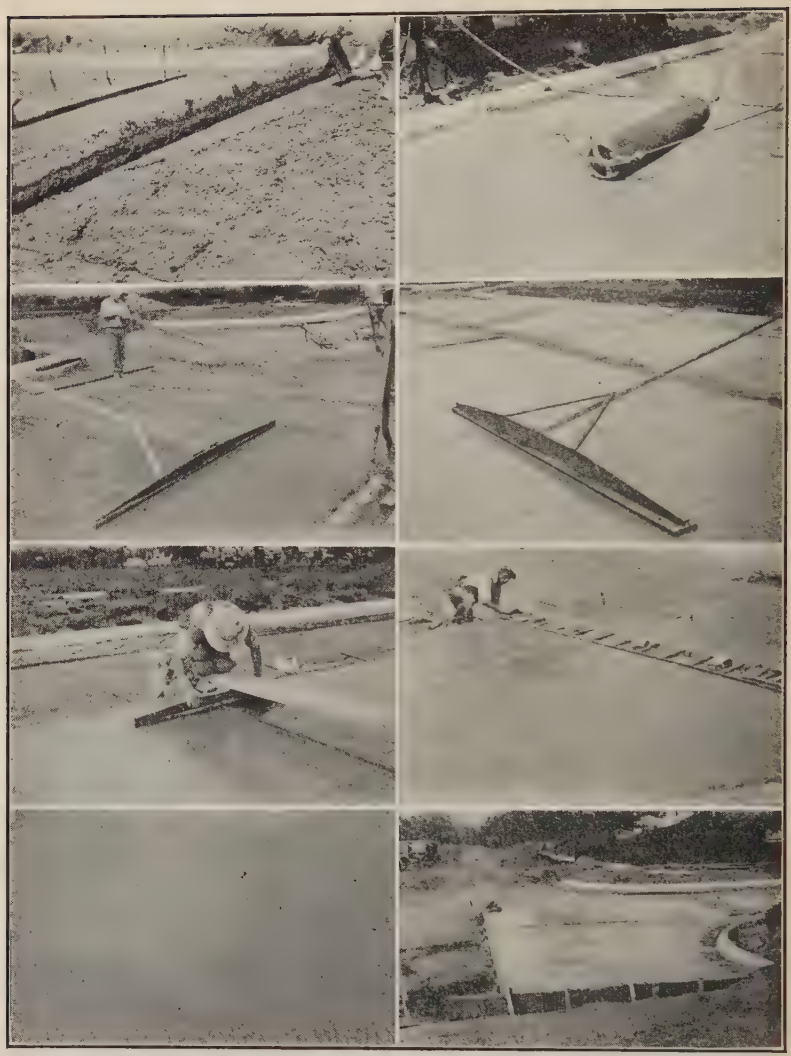


FIG. 80.—Finishing a city concrete pavement. *a*. After concrete is deposited to full depth it is struck off with a templet cut to the exact shape of the finished pavement. *b*. Then it is rolled and struck off again with the templet as indicated previously. *c*. After the concrete has set slightly a 10-ft. straight edge is pulled transversely across the surface to remove any irregularities and the soft concrete which has worked to the surface. *d*. Next the surface is gone over with a 10-ft. long-handled float. *e*. The surface adjacent to the expansion joints must be struck off with a 3- or 4-ft. notched straight edge. *f*. The final operation is to use a canvas belt fastened to a thin bending strip of wood. The last time over with the belt it should be moved longitudinally with no transverse movement. *g*. The appearance of the finished surface. *h*. A good surface at intersections can be most easily secured when poured one-fourth at a time, with forms set to line and grade along the center lines of both streets.

rollers have a tendency to distort the surface especially if the concrete is soft, so that it is advisable to go over the surface again with the strikeoff or with a 10-ft. straight edge. Very good results can be secured with the latter at this stage of the finishing operations. The straight edge should be made of light materials and should be on a long handle so that the entire surface can be reached from either or both sides. Pull the straight edge transversely across the pavement making no effort to dig in or move large amounts of concrete. Its chief purpose is to remove the soupy mixture which has been worked to the surface and to smooth out any irregularities which have developed during the rolling operation. The use of the straight edge in this manner will produce a smooth riding surface. Following the straight edge operation the surface is ready for the belting. Common practice is to make a belt of from one to three thicknesses of canvas and several feet longer than the width of the pavement. This belt is quite flexible and follows the surface without correcting any high or low places. In some work in the city of Champaign, Ill., during the summer of 1927, a new type of belt was developed consisting of one thickness of canvas applied to a thin bending strip of wood. The wood has sufficient rigidity to trim off the high places and carry all extra material along to fill in low spots. A smoother surface was secured with this type of belt than with the ordinary one.

Scaling.—Some trouble has been experienced with scaling on concrete pavements. A thin layer, about $\frac{1}{8}$ to $\frac{1}{4}$ in. in thickness comes loose from the rest of concrete, usually after one or two winters. Various reasons have been advocated and the following explanation seems most logical. Small amounts of dirt and dust exist in all aggregates and are not harmful to the quality of the concrete if uniformly distributed throughout the entire mass of concrete. If an excess of mixing water is used much of the dirt and dust is brought to the surface as this excess mixing water is removed. Not much strength is developed as a result in the top layer and scaling follows.

In order to prevent scaling, (1) the aggregates should be comparatively clean; (2) the amount of mixing water should be only enough to produce a slump of about 1 in. for pavement concrete; (3) the concrete should not be worked any more than necessary to produce the desired surface; and (4) the watery mixture on the surface should be removed before the last steps

in the finishing operations, as shown in Fig. 82. When these precautions have been taken scaling has not resulted.

Protection

Concrete must be portected from heat, wind, rain and cold during the setting period and the first stages of hardening. Heat and wind will dry out the surface and cause the concrete to check or crack. The only damage that rain can do is to marr the surface. Cold can, of course, prevent the concrete from gaining strength rapidly enough and in case of freezing too quickly may stop all possibilities of any gain in strength.

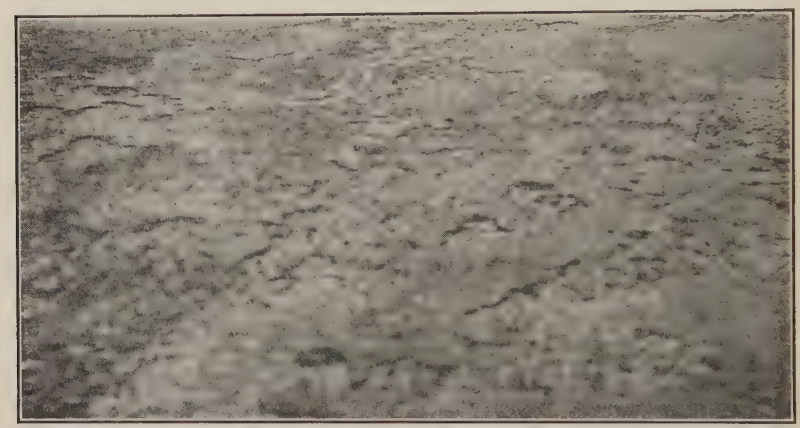


Fig. 81.—A good example of scaling. This pavement was laid in 1923 and the picture was taken in 1927.

Protection from Heat and Wind.—In protecting concrete from heat and wind, the chief purpose is to prevent evaporation of the mixing water. If the cement paste is permitted to dry out during the setting period shrinkage cracks will develop in the concrete. Shrinkage cracks are undesirable because of the consequent weakening of the concrete.

Protection of horizontal surfaces from the wind and sun is most easily accomplished by carefully placing strips of wet burlap or canvas directly on the concrete and then keeping them wet by subsequent sprinkling. Canvas stretched on frames may be used but is hard to handle in strong winds. Frames are also easily broken so that most contractors prefer to use the strips laid directly on the concrete. Canvas or burlap

carefully laid on the surface will not produce objectionable marks on any concrete which is finished with a belt or a wooden float. In cases where a steel trowel finish is desired, the protection must be accomplished in such a way that the covering material does not touch the concrete. Vertical surfaces are protected by the forms and need no special attention.

Protection from Rain.—Rain falling on concrete will not cause a reduction in the strength. The cement in upper surface, however, may be washed out down to the coarse aggregate.

FIG. 82.—Removing thin, watery mixture from surface of concrete pavement to prevent scaling.

More cement paste can be brought to the surface by additional floating, rolling, and belting, provided the concrete is soft enough. If the concrete is too hard to be reworked, nothing much can be done except to give it a flush coat of cement and fine sand. Its appearance is not so good as the regularly finished surface but after traffic has used the pavement a while no difference can be detected.

Protection from the rain is most easily accomplished with canvas. Burlap is not good because of its non-waterproofing qualities. The water can get through the burlap in sufficient quantities to wash the surface quite badly. Most canvas is not 100 per cent waterproof but does keep out a satisfactory amount and is much better than the burlap.

The public generally is a bit skeptical about the quality of concrete which has been rained upon and because of this feeling it is advisable to require the contractor to provide himself with canvas to protect the concrete in case of rain. A nicer appearing surface will result and this is appreciated by the residents along the street. In case of rains of long duration the concrete can be finished underneath the canvas.

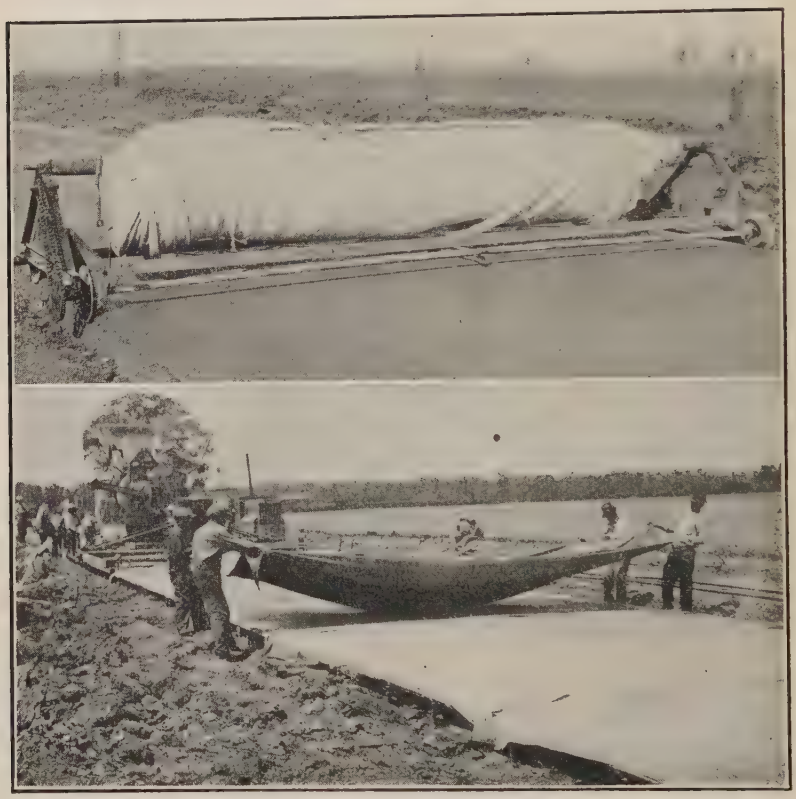


FIG. 83.—*Top.* Carrier for canvas or burlap used in protecting pavement concrete during the first day. *Bottom.* Placing strips of burlap on soft concrete.

Protection from Cold.[1]—Protection of concrete from cold is much more difficult and expensive than from the other items, and failure to do so may result in much greater losses. Concrete which is frozen does not gain strength, and concrete which is just above the freezing point gains strength very slowly, if at all.

[1] See also discussion in Chap. 11 of the effect of temperature on compressive strength.

Concrete which is frozen before it is completely set, most probably is damaged permanently. Sometimes only the surface layer is frozen and later separates from the rest.

The first step in protection from freezing is to raise the temperature of all of the materials well above the freezing point, but not in excess of 125 to 150°F. The hotter the concrete is when placed in the forms the easier will be the problem of protection.

Buildings may be entirely enclosed with canvas and heated with salamanders or live steam. Forms aid in retaining heat and keep out cold. Bridge abutments and piers may be packed

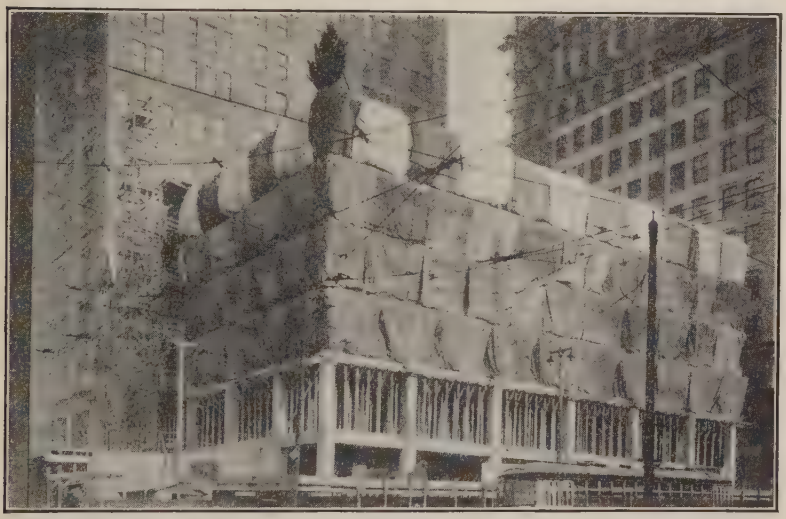


FIG. 84.—Showing protection of concrete on building construction during cold weather.

in straw or enclosed in canvas and the air under the canvas heated. Any method which will keep the concrete from freezing without injuring the concrete is satisfactory.

Protecting pavement concrete is much more of a problem because of the large amount of exposed surface in comparison to its volume. It is so expensive and the results so uncertain that not many attempts are made to pour concrete pavements in cold weather. The subgrade must not be frozen when the concrete is placed, which means that it must be kept from freezing or thawed out. Straw and manure are probably the most effective coverings for protecting concrete against freezing. The former may be placed as soon as the concrete is shaped with

no appreciable amount of marking of the surface. The manure is more effective than the straw but because of its weight may mar the surface if placed as soon as the concrete is shaped.

Calcium chloride may be added to the mixing water in amounts equal to about 2 per cent of the weight of the cement. This will lower the freezing point of the water approximately 5°F. Calcium chloride also has the effect of speeding up the hardening action, so that the concrete will require protection for a shorter time. Calcium chloride should not be depended upon for the lowering of the freezing temperature, and the usual protection of covering and heating should be used.

Calcium chloride should never be placed in the mixer in the solid form, but should be dissolved in the mixing water first. Usual practice is to prepare the calcium chloride solution in barrels and then add a given amount of the solution to each batch. For an example, 2 lb. of calcium chloride are to be added for each sack of cement. The solution is to be prepared in barrels holding 50 gal. The calcium chloride is received in 100-lb. packages. Place two 100-lb. packages of the chloride in about 40 gal. of water and stir until dissolved. Add other 10 gal. of water and stir again. The amount of solution necessary to place 2 lb. of the chloride per bag of cement is found

$$\frac{2}{200} \times 50 \text{ gal.} = \frac{1}{2} \text{ gal.}$$

The amount of mixing water added in the usual manner is reduced then by $\frac{1}{2}$ gal.

Curing

Concrete begins to gain strength as soon as the setting action is complete. Most of the strength acquired by concrete is developed in the first 28 days. Certain strengths are figured in the design of the structure and it is expected that these strengths will be developed within the first 28 days. Any strength developed after 28 days is extra and adds to the factor of safety in the design. The tendency now is to speed up construction by developing the desired strengths in less than 28 days.

One of the methods used to develop strength and resistance to weathering is known as curing. Just how much strength will be added will depend upon conditions, and may vary from 25 to 100 per cent of the strength secured without curing. This increased strength is secured at a comparatively low cost.

Proper curing adds, also, to the wear-resisting qualities of the concrete. Concrete used in pavements is subjected to considerable wear and, therefore, curing of concrete pavements is doubly important. Because of the general relationship, which indicates good wearing qualities with high strengths, there is a tendency to omit proper curing of concrete pavements when the strength test results are higher than felt necessary. High compressive strength in the mass of the concrete under the wearing surface is not necessarily a measure of the wearing qualities of the surface layer. Proper curing of concrete pavements is essential regardless of the strength being developed.

Proper curing will also add to the waterproofing quality of the concrete. The development of additional compressive strength mentioned above produces a concrete which is better able to resist the passage of water through it. This passage of water is normally through the cement paste and not through the aggregate. Anything that will improve the quality of the cement paste, therefore, will improve the waterproofing quality of the concrete.

Concrete in order to gain the greatest amount of strength needs both water and heat. Water is mixed with the cement and aggregates to make a workable mass and to aid in placing. The amount of water required for proper hydration of the cement is equal to about 10 per cent of the weight of the cement, while the amount of mixing water actually used is often in excess of 50 per cent. If the mixing water can be kept in the concrete, there is sufficient water for curing purposes. Curing consists then in preventing the evaporation of the mixing water.

The greatest benefit from curing is secured when the concrete is prevented from drying out for a period of at least 3 days. Valuable results are secured up to about 10 or 14 days. Engineers generally do not consider it worthwhile to keep the concrete wet more than 14 days, even though the desired strength is not then developed. As the concrete develops strength the rate of evaporation is reduced, which in turn helps to retain the moisture in the concrete.

Methods of Curing.—Wherever forms are used they should be left in place as long as possible. In case it is necessary to remove them, the surfaces of the concrete may be kept wet by sprinkling with water. The amount of sprinkling necessary will depend upon the rate of evaporation. The tendency has been to omit

curing of building concrete. Because the buildings are designed with a factor of safety of three or four, there is small chance for a failure of the structure due to improper strength resulting from the omission of the curing. In many cases, however, the factor of safety has been reduced below that figured in the design.

The most difficult problems of curing are found in connection with pavement concrete, where there are large exposed surfaces

Left. Continuous spraying. *Right.* Covering with straw and wetting intermittently.

Left. Ponding. *Right.* Covering with dirt and wetting intermittently.

FIG. 85.—Methods of curing.

open to the sun and wind. This exposed surface also receives the wear of traffic and therefore needs extra quality. Any of the following methods of water curing are generally permitted. Engineers differ on the desirability of the others.

Covering with Earth or Straw.—As soon as the concrete is sufficiently hard, a layer of approximately 2 in. of earth or 6 in. of straw is spread over the surface and kept wet for a period of from 3 to 10 days. The frequency of wetting will depend upon

the rate of evaporation which in turn depends on the material and the temperature and humidity of the air. One to three or four wettings per day of the coverings are necessary.

Whether dirt or straw will be used will depend upon the cost and availability of straw. The labor charge is high in connection with the use of earth. Wet earth curing on city streets may be undesirable if there are many pedestrians desiring to cross the pavement. The surface of the concrete can not be readily cleaned of all the dirt covering which will cause large amounts to get into the drainage system or may become a nuisance to the residents along the street by being blown about.

Ponding.—A method now rarely used is to build dikes across and along the pavement and to place water between the dikes. The chief objections to the method are: the dikes are easily broken; they may need to be quite high or close together because of the slope of the pavement; and the amount of water is excessive compared to the other methods.

Sprinkling.—The surface of the concrete may be kept wet by continuous or intermittent sprinkling. This method has not found general application for pavements.

Calcium Chloride.—Flake calcium chloride may be sprinkled uniformly on the surface at the rate of 2 to 2½ lb. per square yard. The calcium chloride should be applied on the morning following the pouring of the concrete, providing of course rain is not falling. If rain does not fall on the calcium chloride within 4 hours after it is applied, no further applications are necessary.

Calcium chloride is a deliquescent salt and absorbs sufficient moisture from the atmosphere to completely dissolve itself. Just how the calcium chloride functions in curing the concrete is still a matter for conjecture.

The length of time necessary before opening to traffic will depend upon the strength necessary. If strength tests are not made, a safe policy to follow is not to open before the end of 10 days in the summer, 15 days in the late spring and early fall and 21 days or 28 days in early spring and late fall.

Calcium chloride is best spread uniformly with a mechanical spreader. Too much calcium chloride may have a more harmful effect than none at all. Persons with ordinary leather-soled shoes should not walk on the freshly applied calcium chloride, as the chloride will draw all of the moisture out of the leather.

Calcium chloride curing has certain advantages over the other methods mentioned above. Cost of application is comparatively low. Once applied there is no further work necessary.

FIG. 86.—Mechanical spreader for applying calcium chloride.

There is no dirt or muss which affects residents or pedestrians. When the concrete is of the proper strength, the pavement may be opened at once. In the case of dirt or straw covering the

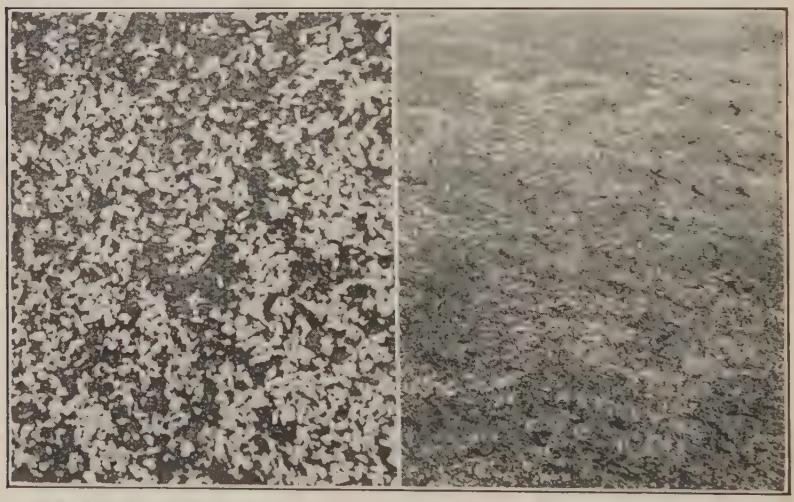


FIG. 87.—Calcium chloride on the surface of a concrete pavement. *Left.* Immediately after application. *Right.* Two hours later. Note uniformity of distribution.

pavement may not be used until the contractor has cleaned away the curing materials. Many contractors prefer to use this

method for the above reasons. Not all engineers, however, permit its use. Certain surface defects, the chief of which is scaling, have appeared on calcium chloride cured pavements and calcium chloride has been blamed. Engineers are divided as to the responsibility for these surface defects. The author's experience has been that calcium chloride properly applied to concrete properly made and placed will give satisfactory results.

Water-glass Curing.—Water glass may be applied to the surface of concrete pavements as a method of curing. The effect is to seal up the surface and thus prevent evaporation. Application is made on the morning following pouring. This method has been chiefly used on vibrolithic concrete pavements. This method has the same advantages as mentioned for calcium chloride.

Questions

1. What time interval may be permitted between mixing and placing of concrete in the forms? What factors influence the time interval?
2. What is meant by central mixing of concrete? central proportioning?
3. Discuss various methods of transporting the mixed concrete from the mixer to its final place in the forms.
4. What is a float finish? trowel finish? What is terrazzo? stucco? art marble?
5. What is the purpose of curing concrete? What methods may be used to cure large flat surfaces? vertical surfaces?
6. What factors should be considered in determining when concrete is ready to be used?
7. Tests do not show much, if any, difference in strengths at early ages for wet and dry cured concrete. Wherein then lies the importance of curing?
8. What effect does temperature during the curing period have upon the strength of concrete?
9. What is meant by checking or hair-cracking of concrete? What is its cause?
10. How may concrete be protected from the cold?

CHAPTER 9

FIELD CONTROL OF CONCRETE

The discussion of field control of concrete is more or less intimately connected with that on production. Methods of production and their relationship to the quality of the concrete produced have been explained in the two preceding chapters. Ways of controlling quality of materials and methods of construction are treated in this chapter.

During the period since about 1915, and especially since 1920, there have been many developments in the field control of concrete. Practices are not standardized today and probably never will be, yet there is much similarity in the work and the ideas of various engineers. The purpose of field control is to secure concrete of the desired qualities. It is not sufficient simply to specify that the contractor shall produce concrete of a given quality. Each shipment of materials must be checked and every detail of construction must be supervised in order to secure the desired results every time. At first, contractors generally resented strict field control of their work, but have since learned that intelligent supervision of their work helps them to get better work, frequently at less cost.

The public is being educated by various agencies to the necessity of testing by properly qualified testing organizations. Much of our advertising today consists in giving results of tests on the materials being advertised. Materials associations through their promotion men are urging public officials to test the materials they are using and to supervise thoroughly the construction work. The state highway departments have developed large organizations for field control. Consulting testing engineers are available to the communities and concerns that can not build up organizations of their own.

Field control of concrete involves the testing of the materials, supervision of the methods of construction, and the testing of samples of concrete prepared from the concrete being used. Inspection is the critical observation of the quality of materials

or a process of construction. The operation of field control on a large scale may include the work of a number of inspectors and testing engineers. On smaller jobs all the operations may be handled by one person.

Field Control of State Highway Work.—In most of the state highway organizations the field control of the materials is in the hands of a bureau or division of materials. This bureau generally has complete charge of all work relating to materials. Inspectors are placed at the various materials plants from which material is being used on any state work. These men remain at the plants during the construction season and have no other duties during that time. Usually the highways department will have a contact man to visit the inspectors at frequent intervals to check up on their work and to settle any difficulties that may have arisen between the plant men and the inspector.

Cement Inspection.—A complete set of tests on portland cement requires 28 days. To wait 28 days before using the cement is usually impracticable, with the result that most cement is accepted or rejected on the basis of the soundness test at the plants where the results have been satisfactory on tests made previously. Where the results of previous tests have not always been satisfactory, it is policy to check particularly on the tests in which the results have been unsatisfactory, even though it may involve holding the material for 28 days.

A sample of cement is usually taken from each carload lot after the cement has been loaded into the car. The soundness test is made immediately and the result sent to the inspector on the job. At regular intervals samples are taken for the purpose of making a complete set of tests. The interval between samples will depend somewhat upon the quality of cement being tested. If the cement from the plant is just passing the specifications, it is advisable to take samples oftener than when the cement is of much higher quality. Samples for check purposes may be taken every day or only every week.

Aggregate Inspection.—Once the quality of the material from a given pit or quarry is established, the only tests necessary in the field are for clay and silt content and for gradation. In some cases the former test is waived on each carload if the results of previous tests have been satisfactory. A sieve analysis determination is easily and quickly made, so that the pit or quarry operator knows usually before the car has started on

its journey whether the material is satisfactory or not. In the case of aggregates it is customary to place a *satisfactory* card on the car.

Reports.—The inspectors keep complete records of all of their tests. Reports are sent each day to the resident engineers or inspectors, as the case may require, on the materials which are shipped or tested that day. Duplicate copies should also be sent to the main office of the bureau of materials and to the field man in charge of the inspection of materials. Generally the men placed on the inspection service are non-technical men or the younger engineers who are just beginning with the department. These men need careful supervision and the system of reports should furnish a check on what they are doing.

Construction Inspection.—Construction inspection is the most important part of the field control work. Unless the materials are properly put together, the structure may fail. With concrete the quality is not known at once and in the interval while it is gaining strength, other portions of the structure are added. The concrete in each portion must be of the proper quality, otherwise the structure may fail when it is finished or nearly finished. Even though a failure in a pavement may not result in loss of life or damage to property it is desirable to do the work correctly the first time. In city work it is often difficult to secure funds for either the original construction or for renewals.

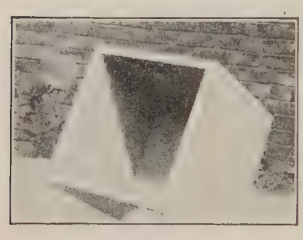


FIG. 88.—The cubic foot box, which is often used on construction work to check the volume of the measuring hoppers.

Many highway departments divide the paving work into sections varying from about 4 to 10 miles in length. An inspector is necessary at the measuring plant and one at the point where the concrete is being deposited. The inspector at the plant on central mixing can easily handle both the measuring and the mixing. If the mixing is done on the road, that inspector may have more than he can attend to thoroughly. He should not have duties which will take him away from the work except for short intervals.

The inspector at the measuring plant should check each batch to see that it has the proper amount of materials in it. Most specifications require the use of automatic measuring

devices, so that the work of the inspector along this line simply requires his observation as to the number of measuresful placed in each batch. Cement is usually handled in sacks which requires a check each time on this item.

If the mixing is done at the measuring plant, the inspector must also check on the time of mix, the charging and unloading of the drum, and on the consistency of the concrete. Timing devices are ordinarily required which lock the discharge apparatus until the proper mixing time has elapsed. Occasional checking of the timing apparatus is all that is necessary. All specifications provide that the materials for one batch shall not be placed in the mixer until all of the previous batch has been discharged. In order to speed up operations there is a tendency on the part of the mixer operator to start the materials for one batch into the mixer before all the concrete of the previous batch is out. This may not be serious if the quantities are small, but should be watched.

Practically all highway work is done with the proportions of the dry materials specified. The amount of water to use is determined on the job and usually no attempt is made to measure it as to the number of gallons. An effort is made, however, to secure the same amount of mixing water in each batch. The inspector at the mixer should, if possible, make consistency tests from time to time, partly as matter of record and partly to show the mixer operator how he is varying the consistency. The slump test is the one most often made in the field. The real benefit of the slump test comes in keeping the concrete of the proper consistency. If the inspector does not have to make the tests and report in to some superior officer, he is quite likely to disregard the consistency entirely. Even though the concrete is of the proper consistency the slump test should be made in order to keep it so.

Several state highway departments are specifying the exact amounts of water and cement and require that the consistency be regulated by means of the gradation and quantity of the aggregate. When the fine aggregate is measured inundated, the amount of water in the inundated sand must be determined so that it can be subtracted from the total amount of mixing water in order to get the amount to be added separately. Since the amount of water in the inundated sand remains practically constant from batch to batch, the initial determination is all

that is usually necessary. In cases where the sand is measured not inundated, either by volume or weight, it is necessary to determine the moisture contents from time to time in order to correct the amount of water being added separately. Variations usually occur during rainy weather or when the material is taken at random from cars or stockpile. Often there is a difference in the moisture content of the sand in the car and in the stockpile. More supervision is required for this method than is usually given under arbitrary proportioning, with the result that better and more uniform concrete is secured.

In other cases, arbitrary proportions and consistency are specified, and once the amount of water required to give that consistency has been determined, the same amount is used in all subsequent batches. The field control operations then are the same as given in the preceding paragraph. Contractors at first objected to the water-cement ratio specification because they did not have information on which to base their bids. The latter method overcomes this objection to some extent.

The inspector at the point where the concrete is being placed must check up to see that the correct amounts of concrete are being placed, that the reinforcing steel is properly placed, and that the concrete is properly finished and cured. Proper methods for each particular job should be described in the specifications. Most highway departments supplement their specifications with a field manual.

The inspector, if given careful supervision, need not be a graduate engineer. Most of his work is the checking of certain items in a given manner. Ordinarily the inspector will not have any authority to make any changes in the regular procedure to fit special occasions. Most road jobs where the contractor develops any speed in construction will require the service of an engineer to lay out the work. The inspector then will be under the direct supervision of the resident engineer.

Frequently there are a number of jobs close to each other so that it is possible to place one man in charge of several sections. This man will spend all of his time giving general supervision to work. It has been found that the man who visits the job occasionally can do much to keep things going properly. Coming on the job fresh and looking it over as a whole, he can catch up points that are being overlooked by the inspectors. New situations and conditions are continually arising which the

inspector often is not capable of handling. Occasionally the inspector and contractor get into trouble with each other and need straightening out.

Field Control on City Paving Work.—The problems encountered on city paving work are similar to those on the country road, so that the necessity is as great in the city as in the country. As a rule, however, not as much is done in the cities, largely because of a lack of finances. The larger cities will have enough work to employ testing engineers, inspectors, and construction engineers all year and it is only in the smaller cities that very little or nothing is done in field control. Some of the larger cities carry on research work as well and use the same organization for both purposes.

For the smaller cities unable to develop their own organizations for field control, there are consulting engineering firms specializing in testing of materials and inspection of construction. In many cities all of the engineering work is done by consulting firms that handle all phases, including estimates, plans, specifications, contracts, inspection of materials, and supervision of construction.

For construction inspection many times the inspector knows nothing of concrete work. Often some property owner along the street is employed or the job is given to some one to repay a political debt. An inspector who is not familiar with concrete may do more harm than good and often unnecessarily causes the contractor extra expenses.

Much better results are secured when the inspectors are employed regularly and are given some training and lots of supervision. Many cities can employ their inspectors for a season at least so that it is worthwhile to spend some time and effort in a systematic training course. Often these men are available for a number of years in succession and if they are satisfactory should be employed, largely because of their experience.

It is necessary to give the inspectors daily supervision, the same as in the country road work. The jobs ordinarily are closer together so that one man can handle more inspectors.

Field Control on Building Construction.—The same items need control on building construction as on the highway work. The problem is different in that the amount of work under the control of an engineering or an architectural firm may be com-

paratively small, and ordinarily, no large organization is developed. If the firm has a number of jobs going at the same time one man may be used to supervise, in a general way, all of the work. An inspector is placed on the job who supervises the handling, measuring, and mixing of the materials, and the transportation, placing, finishing, and curing of the concrete. All these operations are usually taking place in a small area and can be controlled by a small number of inspectors.

Not as much is ordinarily done in the checking of materials for building construction as for the highway work. Architects receive practically no testing training in college and unless they secure an appreciation of its value through sad experiences, not much attention is paid to the selection of materials.

Job Test Specimens.—It is becoming more and more common to make specimens for testing purposes as the concrete is being placed in the forms. As a rule these specimens are cured in the field under the same conditions as the concrete in the structure. Tests are made at various ages to determine the strengths being developed. Frequently, use of the structure is permitted when the test specimens show certain strengths. This is particularly true in connection with highways where the beam test has been developed for use in the field. The strength required before opening to traffic in the case of the pavement will depend upon the thickness of the slab, its design and the loads likely to be imposed. No certain strength can be prescribed as essential in every case. Interpretation and use of field test data should be limited to men of experience in that work.

Methods of preparing and testing these specimens are described in the chapter on testing. Extreme care should be exercised to secure representative concrete and then to cure the specimens under conditions similar to those on the job.

Testing of specimens of concrete in the field furnishes a valuable fund of information for the men on the job and enables them to do their work better. Oftentimes it is possible to develop a little competition between gangs that will improve the quality considerably. Use of a structure when it is ready may reduce construction costs and the only way to determine its readiness is to test the concrete. Tests may also prevent the premature use, an item which is equally valuable.

Questions

Outline the field control methods necessary in carrying on

1. Large highway program by a state highway department.
2. Smaller program by a county.
3. Large program by a large city.
4. Smaller program by a smaller city.
5. In building a large hotel or office building by private interests.

CHAPTER 10

WORKABILITY AND WATERPROOFNESS

Workability

Workability is that property of freshly mixed concrete which is measured in terms of ease of placing, handling, and finishing. The degree of workability necessary will depend upon the nature of the work being done. Concrete to be placed in narrow forms and around reinforcing steel requires one degree of workability, while on the other extreme concrete to be used in massive sections with no steel need not be particularly workable. Each user of concrete must decide for himself what is necessary. The following discussion is intended to aid in arriving at the final answer.

There are a number of factors affecting workability:

1. Cement.
2. Water.
3. Aggregate:
   a. Gradation.
   b. Shape.
4. Mixing.
5. Admixtures.

It is at once apparent from the number of factors involved that it is not possible to derive any mathematical relationships between them and workability. The question of workability is tied in with that of strength and economy of the mixture. Not always is the most workable mix the strongest or most economical, and in many cases workability must come ahead of economy.

The most workable concretes are secured when the maximum size of any of the dry materials is comparatively small in relation to the mass. Workability is improved by increasing the amounts of fine materials in the mixture, but no more fine materials should be used than are necessary to produce the desired workability.

Effect of Cement.—Cement is an exceedingly fine material, about 85 per cent passing the 200-mesh sieve. Increasing the

fineness of grinding should improve to a limited extent the workability of the concrete. The cost of increased fineness is so great that it is not worth while as a medium for increasing the workability of concrete. Increased fineness improves the strength-producing quality and is worth while from that standpoint.

Increasing the amount of cement used in the concrete will increase its workability. In addition to improving workability, strength, durability, and watertightness are improved. If these latter qualities are necessary in addition to that of workability, increasing the cement content of the concrete will accomplish these results. If workability is the only one desired, other methods may prove more economical.

Effect of Water.—For a given mix and materials, the workability may be varied within narrow limits by changing the amount of mixing water. Most specifications are still giving proportions of dry materials and permitting variations in the amount of mixing water to secure the desired workability. A certain amount of water is necessary in order to make the mixture dense and strong as well as placeable. There is a small range of amounts of mixing water which produce workable concretes. Beyond this range the concrete becomes unworkable as the amount of mixing water is increased. Some construction men think that the only way to secure workability is by adding mixing water, whereas beyond a certain point the addition of water makes unworkable concrete. There is a correct amount of water for each combination of materials and that amount is usually smaller than the average man on the job thinks. Often the use of less mixing water will make a more workable concrete.

On many construction jobs the chuting method is employed to distribute the concrete and water is used as the principal lubricant to move the concrete in the chutes. This excess water then produces a concrete in the forms which is difficult to puddle and make into a uniform mass. The space occupied by the mixing water is not filled with cement paste or mortar and if next to the forms presents an unsightly appearance. In addition the strength of the concrete is seriously affected. A 1:2:4 concrete, at 70°F., may have it sstrength varied 2,000 lb. per square inch by varying the amount of mixing water. Here is a case where much strength may be sacrificed in order to secure a degree of workability to aid in the movement of concrete. Much better results can be secured by limiting the amount of

mixing water and proportioning the other materials so that proper workability can be obtained.

Often it is necessary to haul mixed concrete in trucks distances up to about 5 miles. If the concrete is too wet there will be a segregation of the materials in the truck due to jolting, the coarse materials settling to the bottom and the water and fine materials rising to the surface. For concrete to be hauled any distance it is important that the correct amount of water be used to prevent segregation. The correct amount can best be determined by trial on the job.

Effect of Aggregates.—Gradation and shape of the aggregate have a bearing on the problem of workability. Sometimes the gradation need be varied in order to counterbalance the effect of shape. More can be done with gradation and shape to improve workability than is generally realized.

Gradation.—The gradation of an aggregate gives the proportions of the various sizes of particles. Aggregate is used with cement paste to cheapen its cost. The best gradation from this standpoint is the one that extends the cement paste the most. This gradation, however, may not produce a concrete which can be handled and placed easily and cheaply. A balance must be struck between workability and amount of concrete produced.

For the moment, consider the problem as one in which the volume of cement and water are kept constant, and the gradation of the aggregate varied to see what the effects upon workability and amount of concrete are. Instructions for the performance of such an experiment will be found in Test 37. The cement paste is mixed first and then aggregates of different gradations are added until the desired workability is secured.

In the first case only sand is added. A workable mix is secured but not much concrete is produced. Suppose that in the next case only aggregate larger than $\frac{1}{4}$ in. is used. The mix is so unworkable that it is out of the question for use in construction. Next let us try equal parts of sand and coarse aggregate. The concrete is workable and the quantity is much larger than in the first case. Observation indicates that the proportion of coarse aggregate may still be increased without sacrificing workability. In the fourth trial make the amount of coarse aggregate one and one-half times the amount of sand. Again the concrete is workable and the amount is greater than in the preceding case. It is observed, however, that the propor-

tion of coarse aggregate may not be increased much more without sacrificing some in workability. For the fifth trial use twice as much coarse as fine aggregate. The concrete will be workable for some purposes and the amount in most cases will be a little larger than before. If another trial is made with 3 times as much coarse as fine, it will be observed that the workability and amount of concrete are much reduced. It would appear then that the amount of coarse aggregate should be from one and one-half to two times the amount of fine aggregate. Proportions as used today lie within that range.

A similar problem may be tried in which the maximum size of aggregate is varied from ¼ to 2½ in. The aggregate in each case should be graded between the maximum and minimum sizes. As the maximum size is increased, the workability of the concrete will be decreased, while the amount produced will be increased. Somewhere between ¼ and 2½ in. will be found the maximum size which can be used for various kinds of work. For reinforced concrete the maximum size is often limited to ¾ or 1 in., while for pavements 2 or 2½ in. is usually set as the limit. On some reinforced concrete work it would be possible to increase the maximum size of aggregate without making the concrete unworkable.

In order to use drier consistencies and larger coarse aggregate in heavily reinforced members on the Wacker Drive improvement in Chicago, mortar mixes were placed first in the bottom of columns and walls. The same water-cement ratio was used as in the concrete and sand was added to the cement paste until the desired consistency was secured. This mixture was placed in the forms first in sufficient quantity for the entire wall or column. Concrete was then poured into the mortar and puddled so that the former settled to the bottom. As the concrete was added the mortar rose higher and higher and filled in around the steel and into the corners of the forms. In the beams and slabs, the mortar was placed first and to a depth which covered the reinforcing steel. Smooth surfaces were secured and the steel was thoroughly embedded in the concrete.

Shape of Aggregate.—Practically all research work on concrete has been done with sand as the fine aggregate and pebbles as the coarse aggregate, so that much of our knowledge is based on rounded particles. Crushed stone is often used as the coarse aggregate and the question is often asked which is the better.

Each has certain characteristics which makes it desirable in certain cases. The rounded particles of the pebbles produce a more workable concrete than do the angular pieces of crushed stone, when the two materials have the same gradation. When crushed stone is used as a coarse aggregate the gradation of the aggregate may need to be changed in order to produce the same degree of workability. It will be necessary to increase the proportion of fine aggregate, and ordinarily the slight change in gradation may be made without any noticeable effect on the quantity of concrete produced.

Effect of Mixing.—The purpose of mixing concrete is to secure a uniform distribution of the cement paste through the aggregate. For any given mixer the thoroughness is a function of the length of mixing time. Most specifications call for 1 min. of mixing. Increased workability may be secured by increasing the time of mixing. When concrete is hauled from a central mixing plant, increasing the time of mix will produce a more workable concrete with less water. Decreasing the amount of mixing water cuts down on the amount of segregation due to hauling and increases the strength of the concrete.

Effect of Admixtures.[1]—Certain admixtures are available for inclusion in concrete for the purpose of improving the workability. All these admixtures are extremely fine materials and without question do make the lean mixes more workable. The richer mixes contain more cement and hence cannot have their workability improved as much. If the admixtures are used in small quantities no decrease in strength is likely to result. The question uppermost in the minds of engineers and contractors is whether the use of admixtures is the cheapest way to secure the desired results. Emphasis has been placed on the value of increasing the coarseness of the aggregate, with the result that much in the way of workability has been sacrificed in order to increase the compressive strength a slight amount. The increase in coarseness of aggregate has in many cases been carried so far that unworkable mixes have resulted and now various remedies are being advocated to cure the evil. No satisfactory laboratory method has been devised for measuring workability, which makes it difficult to determine with any degree of exactness the workability of the various combinations of the different materials. Even if a satisfactory apparatus were available there

[1] See Chap. 5 for discussion of various admixtures.

would be some question as to the relation of laboratory results and field requirements.

The admixtures most commonly used for improving workability are hydrated lime and diatomaceous silica. The former is used in amounts up to 5 lb. per bag of cement, and the latter usually at the rate of 2 to 3 lb. per bag.

Contractors using admixtures report that they get, especially with the leaner mixes, more uniform concrete from batch to batch than when they do not use the admixtures. Because of the extreme fineness of these materials they reduce to a minimum the effects of small variations in amounts of mixing water on the consistency of the concrete. Moisture contents in aggregates vary from batch to batch and cannot be compensated by changing the amount of water added.

The use of an admixture requires additional attention at the mixer and is objectionable from that standpoint. Ordinarily, however, no additional help is necessary. Both admixtures are added dry as the other materials are being placed in the drum.

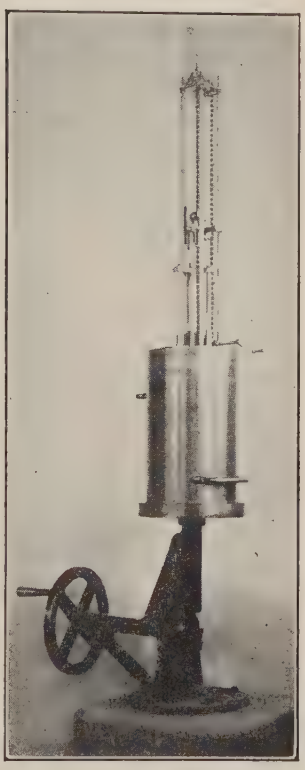


FIG. 89.—A type of workability apparatus used at the United States Bureau of Standards.

Measurement of Workability.—A number of investigators have been working to develop an apparatus to measure the workableness of concrete. The type of apparatus which promises to give the best results is one which uses the penetration of a rod as the measure of the workability. In recent tests,[1] a rod was driven 11 in. into the concrete by a series of blows, as in the case of a pile driver. The amount of energy necessary was taken as the measure of the workability.

The slump and flow tests are not suited for measuring workability. Their use is largely limited to the control of consistency

[1] SMITH, GEORGE A. and GEORGE CONAHEY, "Workability," *Proc. Am. Concrete Inst.*, 1928.

on construction work. Two concretes of the same slump may have much different workability values due to any one of the various items discussed above.

Waterproofness

Waterproofness of concrete may be accomplished in any of the following ways:

1. Special waterproof cements.
2. Admixtures.
3. Richer mixes and careful gradation of the aggregate.
4. Small amounts of mixing water.
5. Proper curing.
6. Application of bituminous coatings to the surface.

Waterproofing of concrete is desirable in order to increase the durability of the concrete or is necessary in order that it may be used to hold water. Concrete which absorbs water easily is likely to disintegrate due to the wetting and drying action, or to freezing and thawing while wet. Concrete is often used where it is necessary to hold the water either inside or outside the structure, in which case, flow of water through the concrete must be prevented. Various methods used will be discussed briefly in the following paragraphs.

Waterproof Cements.—As indicated in Chap. 3, there are available certain cements which have a waterproofing material added to the clinker as it is being ground. Waterproof cements are used in the same manner as the standard brands. Care should be exercised, however, in selection of materials, mixing, placing, and curing. Waterproof cement alone will not make waterproof concrete.

Admixtures.[1]—There are a number of patented admixtures on the market which are claimed to increase the watertightness of the concrete in which they are used. Hydrated lime is also used for this purpose. Normally, 3 to 5 lb. per bag of cement are used for waterproofing purposes.

Richer Mixes and Careful Gradation of the Aggregate.—Passage of water through or into concrete is normally through the cement paste and not through the aggregate. A 1:2:4 mix, which is rated as 2,000 lb. concrete at 28 days, is almost universally used for reinforced concrete, and as prepared on many jobs is not watertight. Improving the quality of the cement paste

[1] See Chap. 5, for discussion of admixtures.

and increasing its thoroughness of distribution through and bonding to the aggregate will increase the imperviousness of the concrete. By carefully grading the aggregate and then mixing it thoroughly with a cement paste of good quality a watertight concrete may be made.

Smaller Amounts of Mixing Water.—The quality of the cement paste mentioned above may be increased for waterproofing purposes by using a minimum amount of mixing water. Small amounts of mixing water produce concretes which do not segregate in handling and which may be easily compacted into a solid dense mass. The excess water forms voids in the cement paste which permit the flow of water through the paste. By using a stiff consistency and thus eliminating excess mixing water, more waterproof concrete can be secured.

Proper Curing.—Proper curing aids materially in the developing of a watertight concrete. If the concrete is permitted to dry out soon after pouring, the cement paste does not become so dense as when it is kept wet. The denser the cement paste, the greater will be the resistance to the flow of water through the concrete.

Application of Bituminous Coatings.—Concrete may be waterproofed also by the application of bituminous coatings to the surface which is wet first. A light water-gas tar may be used which penetrates somewhat into the concrete or heavier tars or asphalts may be applied which form an impervious layer over the surface.

Questions

1. What is meant by workability? How is it measured?
2. Name and discuss various items affecting workability.
3. How may waterproofness of concrete be secured?

CHAPTER 11

HIGH EARLY STRENGTH CONCRETE

The adoption of the standard specifications for portland cement by the American Society for Testing Materials, in 1904, permitted the manufacturers to give their attention to the development of quantity production, which they have done remarkably well as is evidenced by the figures in Table 2. Quality has gradually increased, as is indicated by the increasing of the minimum requirements in 1916 and 1926. During the World War, concretes of high early strengths were used and since then there has been an insistent demand on the part of the engineers and construction men for higher quality cement or for a method of making concrete of required strengths at ages earlier than 28 days.

Because nearly all of our strength data are based on 28-day tests, the tendency has been not to use the concrete for that length of time. The World War taught people to do things in a hurry, with the result that the public is demanding use of the concrete structures in a shorter length of time. The possibility of securing strengths in from 5 to 10 days or less, sufficient to permit full use of the concrete, has appealed to the American public. Frequently the earning power of a building during the time saved far exceeds the cost of the extra efforts made to secure the necessary concrete strengths. The problem of obtaining a certain strength at given age is largely a matter of materials, proportions, and curing.

High-early-strength concrete is a term not easy to define. The commonly accepted meaning is a concrete which has greater strength at ages under 7 days than has ordinary concrete at the same ages. Most reinforced concrete design is based on an ultimate strength in the concrete of 2,000 lb. per square inch. A 1:2:4 concrete which has generally been rated as giving this strength in 28 days, would have a strength of approximately 1,000 lb. per square inch at 7 days. Concrete of this quality is accepted by many as the standard by which to judge all others.

Relationship between 7- and 28-day Strengths for Standard Portland Cement Concrete.—The relationship between 7- and 28-day strengths of concrete or mortar using standard brands of portland cement is expressed by the formula

$$S_{28} = S_7 + 30\sqrt{S_7},$$

in which S_{28} = strength at 28 days and S_7 = strength at 7 days. This formula was developed by W. A. Slater and is often known

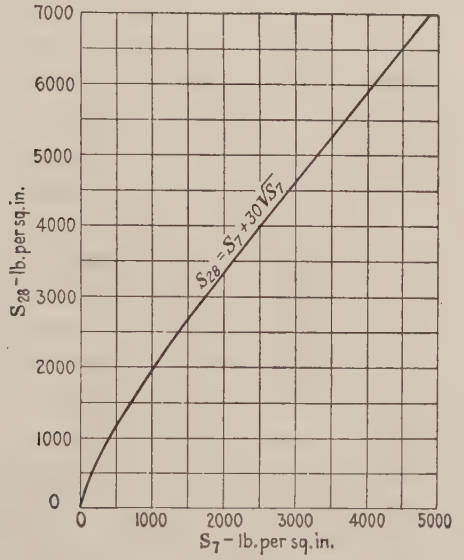


FIG. 90.—Slater curve showing relationship between 7- and 28-day strengths of portland cement concrete. Curve is based on tests made using standard brands of portland cement and moist curing at 70°F.

as the Slater formula. It might be used as the basis for determining whether a cement was of the high early strength type or not, since normally the high-early-strength cement concretes do not continue to gain rapidly after 7-days. Standard brands of portland cement function according to the curve regardless of cement content.

Factors Affecting the Rate of Gaining Strength.—Concrete gains strength with age. The rate, however, is a function of a number of items:

1. Richness of mix (or value of water-cement ratio).
2. Characteristics of the cement.
3. Curing conditions:

a. Moisture.
b. Temperature.

Because all of the items bear on the strength at any age, it is necessary when studying the effect of any one, to keep the others constant. In the following discussions, it is assumed that the items other than the one under discussion are kept constant.

Richness of Mix.—With the same consistency of the concrete, the richer mixes develop greater strengths at all ages. With the richer mixes the ratios of water to cement are lower for the same consistency of concrete. A 1:2:3 mix will have a greater strength than a 1:2:4, which in turn will have a greater strength than a 1:3:5. In Table 12 are given the results of a series of tests made by the author to show the effect of richness of mix on the rates at which the concrete would gain strength.

TABLE 12.—COMPARISON OF THE RATES OF GAINING STRENGTH OF CONCRETE MADE WITH VARIOUS WATER-CEMENT RATIOS

Values in pounds per square inch				
Age, days	Water-cement ratios			
	0.6	0.8	1.0	1.2
1	355	460	265	95
3	2,600	1,910	1,120	710
5	3,770	2,950	1,710	1,390
7	3,940	3,580	1,910	1,540
14	5,200	4,280	2,790	2,190
28	6,100	5,000	3,345	2,780

Each value is the average of the results of three 6- × 12-in. cylinders. Concrete for approximately 6 cylinders was mixed in a tilting drum mixer for 2 min. Cylinders were molded in the standard manner. Cylinders remained in the molds for 24 hours, at the end of which time they were placed in the moist room until tested. Cylinders were tested in a 200,000-lb. hydraulic machine. Temperature of moist room was 70°F.

The cylinders with the 1:2:3 mix and the 0.8 water-cement ratio were made first. The same ratio of fine to coarse aggregate was used in the other mixes. The amount of aggregate to use was determined by mixing first a cement paste of the proper proportions and then adding the aggregate until the desired consistency was secured. The 0.6 water-cement ratio required cement at the rate of about 8½ bags to 1 cu. yd. of concrete, 0.8 water-cement ratio at the rate of 7 bags, the 1.0 ratio at

the rate of 5½ bags, and the 1.2 ratio at the rate of 4 bags. According to the data 2,000-lb. concrete can be obtained at ages varying from 2½ to 12 days, depending upon the mix (or water-cement ratio).

In making use of these data it should be borne in mind that the curing temperature was 70°F. and that the cement gave somewhat higher strengths than does the average portland cement. Other temperatures might give different results. The only safe way to determine strengths on a job is to make tests on the concrete as it is being used.

Effect of Characteristics of Cement.—The characteristics of cement will play an important role in the rate of gaining

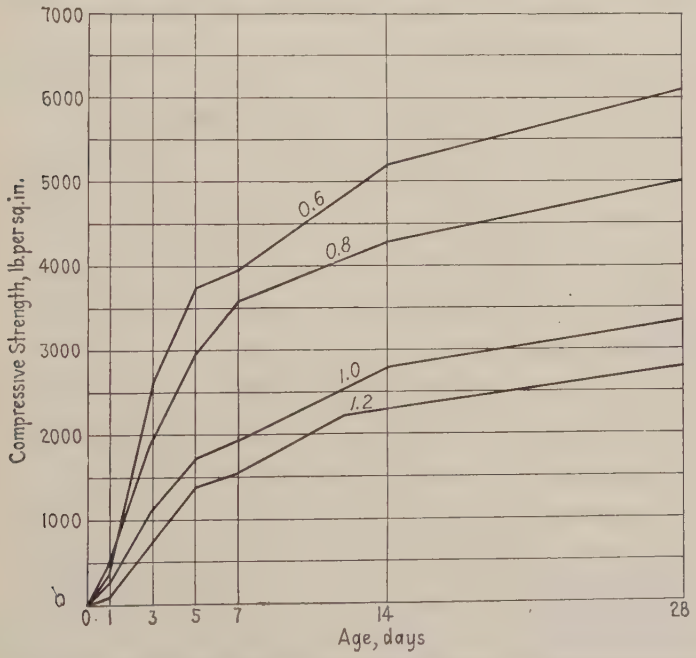


FIG. 91.—Graphical presentation of data given in Table 12 (see table for description of tests).

strength. Cements have been made to meet the minimum requirements of the A.S.T.M., but no manufacturer formerly made any point of it in his advertising if his cement should be of a higher quality than the minimum required. Certain developments in the methods of manufacture have improved the strength-gaining property. Longer kilns have made it possible to use a

wet mixture of raw materials, with the result that more uniformity can be maintained in the finished product. Special blending bins are accomplishing the same result for the dry process of manufacture. Better grinding machinery is being developed which permits finer pulverizing of the clinker. Increasing the percentage of cement passing a 200-mesh sieve increases the amount of strength-gaining materials. Manufacturers are also paying more attention to the selection of the raw materials.

All these improvements in manufacturing methods have increased the quality of portland cement. The quality of cements in 1928 is better than it was in 1918 or 1919. Manufacturers who spend money to improve the quality of their products are inclined now to make use of this fact in their advertising. Since the public is interested in using concrete as soon as possible, the manufacturers are featuring the possibilities of their cements at ages of from 3 to 10 days.

Special Portland Cements.—In addition to improving the quality of the standard brands, several manufacturers have brought out special cements which develop greater strengths, especially at the earlier ages. Without doubt there will be considerable progress made within the next few years in the developments of portland cements. For a discussion of these materials see Chap. 3 on special cements.

Until more is known of what these cements will do, it is well to go slow with their use. Admixtures should not be used without first determining the effect. Careful conservative use of the special cements will help materially in their development, while a few failures may completely eliminate them from the construction field.

Compression tests on aluminate cement concrete show that it has greater strength at the end of 24 hours than has similar portland cement concrete at the end of 28 days. A high point in the strength curve seems to be reached at 3 or 5 days; 28-day strengths are frequently lower than the 3- or 5-day strengths. Much heat is produced as the cement is setting and unless kept wet the concrete is likely to be permanently injured due to the heat developed. Not all long time strength tests have been satisfactory. Before using this cement it is well to be familiar with its characteristics and know how to handle it. Strength results for a 1:2:3 mix by volume and an 0.8 water-cement ratio are given in Table 13.

TABLE 13.—COMPARISON OF THE RATES OF GAINING STRENGTH OF CONCRETE MADE WITH VARIOUS TYPES OF CEMENTS

Age, days	Values in pounds per square inch					
	Standard portland cements			Special portland cements		Aluminate cement
	1	2	3	4	5	6
1	460	755	775	1,010	1,000	4,310
3	1,910	2,415	1,830	3,620	3,400	6,310
5	2,950	2,870	2,770	4,475	4,140	5,955
7	3,580	3,375	3,110	4,870	4,520	6,010
14	4,280	4,370	3,780	5,220	5,230	6,130
28	5,000	4,610	4,850	5,360	5,510	5,270

Each value is the average of the results of three 6- × 12-in. cylinders. Concrete for approximately 6 cylinders was mixed in a tilting drum mixer for 2 min. Cylinders were molded and capped in the standard manner. Cylinders remained in the molds for 24 hours, at the end of which time they were placed in the moist room until tested. Cylinders were tested in 200,000-lb, hydraulic machine.

Mix in each case was a 1:2:3 by volume with an 0.8 water-cement ratio.

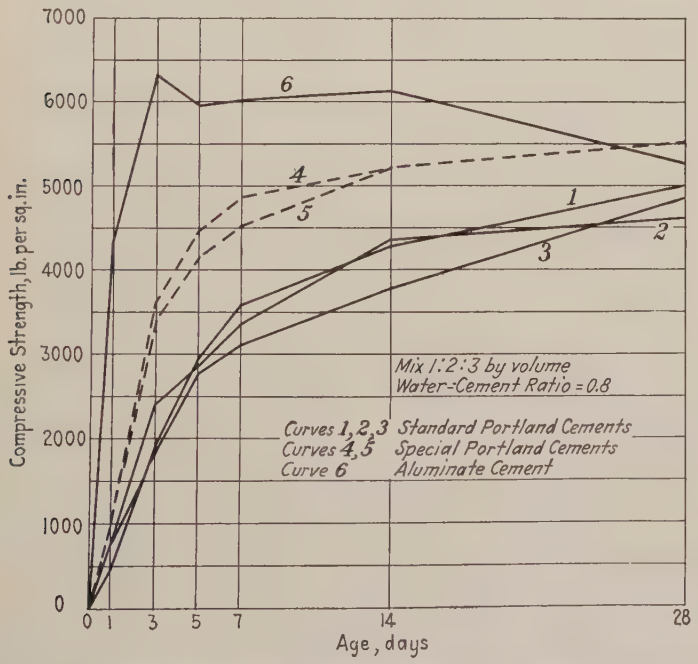


FIG. 92.—Graphical presentation of data given in Table 13 (see table for description of tests).

Results of a series of tests, by the author in 1927 and 1928, to compare the rates of gaining strength of concrete made with various cements are given in Table 13. The mix used was a 1:2:3 by volume with an 0.8 water-cement ratio. Richer mixes with smaller water-cement ratios will produce greater strengths as indicated previously and as shown in Fig. 91.

Effect of Curing Temperature.—The average person appreciates fairly well that increasing the richness of mix increases the

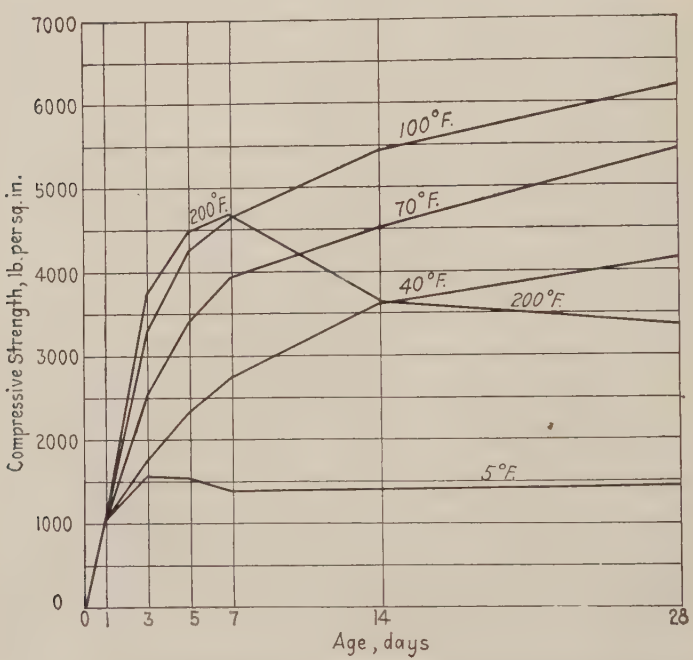


FIG. 93.—Graphical presentation of data given in Table 14 (see table for description of tests).

strength of the concrete, and that different results can be secured with different cements, but has little conception of the effect of curing temperatures. Standard laboratory tests are made at a temperature of 70°F. Increasing the temperature increases the strength and decreasing the temperature decreases the strength. Concrete which is frozen before it sets is generally considered not to be able to develop any strength later on.

The results of a series of tests to determine the effect of curing temperatures on the strength of concrete of the quality ordinarily

used in pavements are given in Table 14. The concrete was made at an air temperature of 70°F. and remained in the molds 24 hours. The cylinders then remained in the curing temperature until just before testing with the exception of the cylinders which were frozen. They were thawed out in a water bath. From Fig. 93 it is seen that temperature does make considerable difference in the amount of strength at the various ages. For the 28-day strengths each degree change in temperature affected the strength about 35 lb. per square inch.

A. R. Lord reported[1] that in connection with the Wacker Drive improvement they observed that for each degree change in temperature the strength of the concrete was affected 50 lb. per square inch. The mixes on Wacker Drive were leaner than in the series reported in Table 14. It is to be expected that greater effects per degree change in temperature will be observed for the weaker concrete than for the stronger.

TABLE 14.—COMPARISON OF THE RATES OF GAINING STRENGTH OF CONCRETE CURED AT VARIOUS TEMPERATURES

Age, days	Values in pounds per square inch				
	5°F.	40°F.	70°F.	100°F.	200°F.
1			1,005		
3	1,555	1,740	2,530	3,280	3,730
5	1,545	2,335	3,410	4,260	4,470
7	1,395	2,730	3,940	4,650	4,670
14	1,415	3,600	4,520	5,440	3,650
28	1,460	4,140	5,440	6,200	3,370
49					3,430

Each value is the average of the results of three 6- × 12-in. cylinders. Concrete for approximately 6 cylinders was mixed in a tilting drum mixer for 2 min. Cylinders molded and capped in the standard manner. Cylinders remained in the molds for 24 hours, at the end of which time they were placed in the curing container. Curing temperatures were secured as follows: 5°F. in an electric refrigerator; 40°F. in an ice chest; 70°F. in the regular moist room; 100°F. in a water bath; and 200°F. in steam. Frozen cylinders were thawed out before testing. Cylinders were tested in a 200,000-lb. hydraulic machine.

Mix in each case was a 1:2:3 by volume with an 0.8 water-cement ratio. A standard portland cement was used.

Effects of Moisture during Curing.—Keeping the concrete wet during the first week will greatly increase its strength. Concrete

[1] LORD, A. R., "Notes on Wacker Drive," *Proc. Am. Concrete Inst.*, p. 59 (1927).

which has had no moisture during curing will be from one-fourth to one-third weaker than concrete which has been kept wet.

Effect of Calcium Chloride.—Calcium chloride or calcium oxychloride is sometimes used in the mixing water to aid in the development of early strengths and to hasten the setting. The chloride should always be dissolved in the mixing water and never be put in the mixer in its solid form. The amount of additional strength developed is more or less uncertain because of the fact that different cements react differently with the same amount of calcium chloride. It is well to check first with tests the results that can be secured. Two per cent of the weight of the cement is usually dissolved in the mixing water.

Conclusions on Early Strength.—Almost any reasonable strength can be secured at any time with standard or special portland cements. Usable 1-day strengths are rather expensive and usually not counted upon. By observing the best practices as given in the chapters on mixing, placing, and curing, certain small increments of strength may be added to those secured through the use of increased cement contents or special cements. At the present stage of development it is not wise to count too heavily upon early strengths unless test specimens are made to check the actual strengths against those estimated. More data should be available on the effect of temperatures above 100°F. before attempts are made to heat the aggregates or concrete above that point.

Questions

1. The 7-day strength of concrete using a standard portland cement is 1,600 pounds per square inch. What will be the probable 28-day strength based on the Slater formula and 70°F. curing?
2. It is desired to have 3,000-lb. concrete for a pavement at the end of 4 days. The concrete is being laid in the hot part of the summer. What water-cement ratio is likely to produce this strength? Base answer on figures in this chapter. What water-cement ratio should be used for early spring or late fall construction for the same strength and age?
3. What is the effect in pounds per square inch per degree of temperature for the standard portland cement concrete values given in Table 14 and Fig. 93? If the materials had been other than 70° F. at the beginning of the tests, what would be the effect on the resulting strengths?
4. What is high early strength concrete?
5. What are the factors affecting the rate of hardening of concrete?

CHAPTER 12

ESTIMATING QUANTITIES OF MATERIALS FOR CONCRETE

If the volumes of the particles of cement and the aggregates and the volume of mixing water used are known, the amount of concrete produced from these quantities of materials may be estimated, since concrete is a mixture of cement, water, and aggregate. In the mixtures in which the slump is between ¼ and 2 in., there may be a small percentage of air voids. These should not exceed more than about 3 per cent of the volume of

FIG. 94.—Concrete is often used to build pavement bases for other types of wearing surfaces. Note that the concrete is being cured (with calcium chloride) the same as when the concrete is used as the wearing surface.

the concrete. All the voids are usually filled with water. If the air voids are neglected, the error will be on the safe side because the quantities of materials per cubic yard of concrete will be slightly greater than if a small allowance is made for the air voids.

In order to estimate the quantity of concrete produced from given amounts of materials it is necessary to know the proportion of the bulk volume of a material which is solid. The solid volume is equal to the bulk volume minus the volume of voids. The percentage of voids may be measured directly or com-

puted when the weight per cubic foot and specific gravity are known. The formula for percentage of voids is

$$\text{Percentage of voids} = \frac{\text{Sp. gr.} \times 62.355 - \text{wt. per cubic foot}}{\text{Sp. gr.} \times 62.355} \times 100$$

Table 16 and Fig. 97 give values for percentages of voids for various values of specific gravity and weights per cubic foot.

TABLE 15.—SPECIFIC GRAVITIES OF VARIOUS AGGREGATES

Material	Specific gravity		
	Minimum	Maximum	Average
Sandstone	2.40	2.50	2.45
Sand	2.60	2.70	2.67
Limestone	2.60	2.70	2.65
Granite	2.65	2.75	2.70
Marble	2.50	2.90	2.70
Trap	2.80	3.00	2.90
Cinders			1.50

Cement.—The proportion of solids per sack of cement is fairly constant, since the amount of cement in each sack is weighed and the specific gravity of cement does not vary to any extent. A sack of cement weighing 94 lb. net is generally considered to be 1 cu. ft. Some engineers, however, consider 94 lb. as only 0.95 cu. ft. Proportions based on the latter assumption will require more cement per cubic yard than will the same proportions based on the former. Specific gravity varies from about 3.10 to 3.15. The value 3.12 is frequently taken and will be used in these computations. Substituting 94 lb. and 3.12 in the formula in the preceding paragraph, the percentage of voids is found to be 52. The percentage of solids then is 48. A cubic foot of cement, measured by bulk volume, has only 0.48 cu. ft. of solids in it. This value may be used for any cement.

Aggregates.—Aggregates vary more than do the cements so that it is not possible to use average values so freely. Most sands have specific gravities between 2.60 and 2.70, and weights per cubic foot between 100 and 120. A well-graded coarse sand will weigh about 115 lb. per cubic foot and will contain about 30 to 31 per cent voids.

Coarse aggregates vary more than the sands. The range of specific gravities is from 2.50 to 2.90 and the weights per cubic

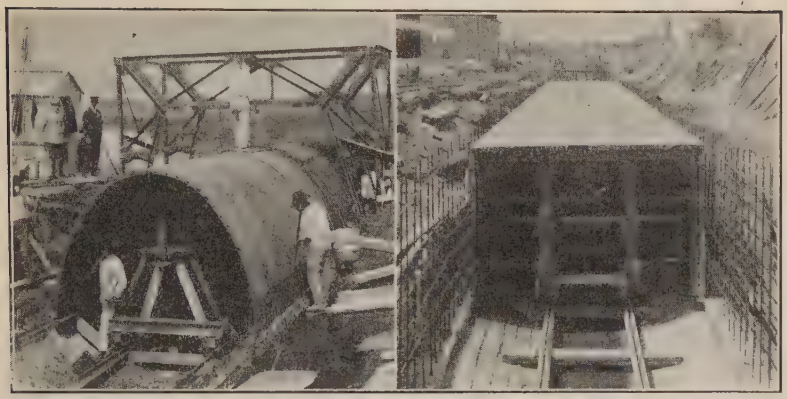


FIG. 95.—Traveling forms can be used to advantage where the cross-section remains the same for some distance.

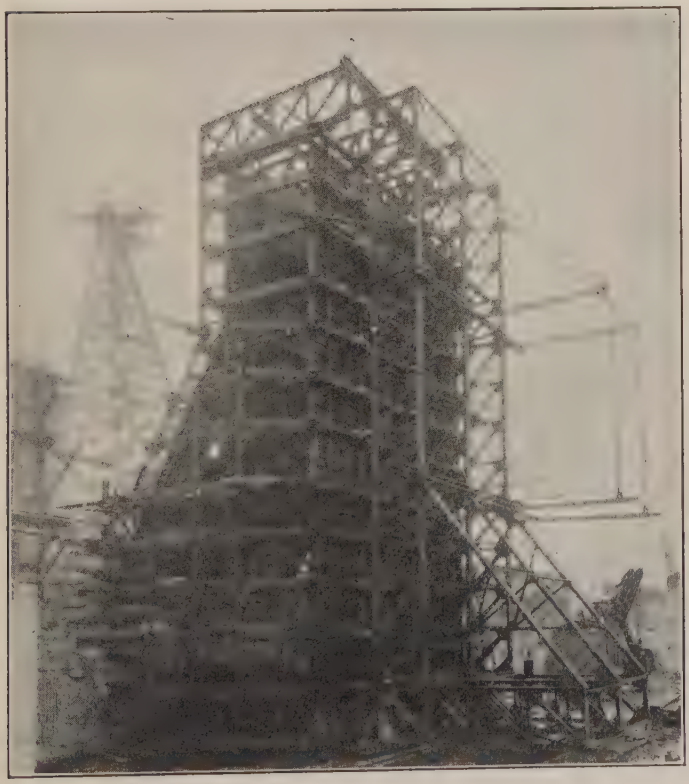


FIG. 96.—Forms for lock at Lockport, Ill.

foot from 90 to 120 lb. Combinations of fine and coarse aggregates will weigh more than either individually and will ordinarily have less voids.

Values of specific gravity for various materials are given in Table 15.

TABLE 16.—PERCENTAGES OF VOIDS FOR DIFFERENT WEIGHTS OF AGGREGATE PER CUBIC FOOT AND SPECIFIC GRAVITIES

Specific gravities	62.355 × specific gravity	Weights per cubic foot											
		90	95	100	105	110	115	120	125	130	135	140	145
2.50	155.89	42.3	39.1	35.9	32.6	29.4	26.2	23.0	19.8	16.6	13.4	10.2	7 0
2.55	159.00	43.4	40.3	37.1	34.0	30.8	27.7	24.5	21.4	18.2	15.1	11.9	8.8
2.60	162.12	44.5	41.4	38.3	35.2	32.1	29.1	26.0	22.9	19.8	16.7	13.6	10.6
2.65	165.24	45.5	42.5	39.5	36.5	33.4	30.4	27.4	24.5	21.3	18.3	15.3	12.2
2.70	168.36	46.5	43.6	40.6	37.6	34.6	31.7	28.7	25.8	22.8	19.8	16.8	13.9
2.75	171.48	47.5	44.6	41.7	38.8	35.9	32.9	30.0	27.1	24.2	21.3	18.4	15.4
2.80	174.59	48.5	45.6	42.7	39.8	37.0	34.1	31.3	28.4	25.5	22.7	19.8	16.9
2.85	177.71	49.4	46.5	43.7	40.9	38.1	35.3	32.5	29.7	26.8	24.0	21.2	18.4
2.90	180.83	50.2	47.5	44.7	41.9	39.2	36.4	33.6	30.9	28.1	25.3	22.6	19.8

The percentage of solids is equal to 100 minus the percentages of voids.

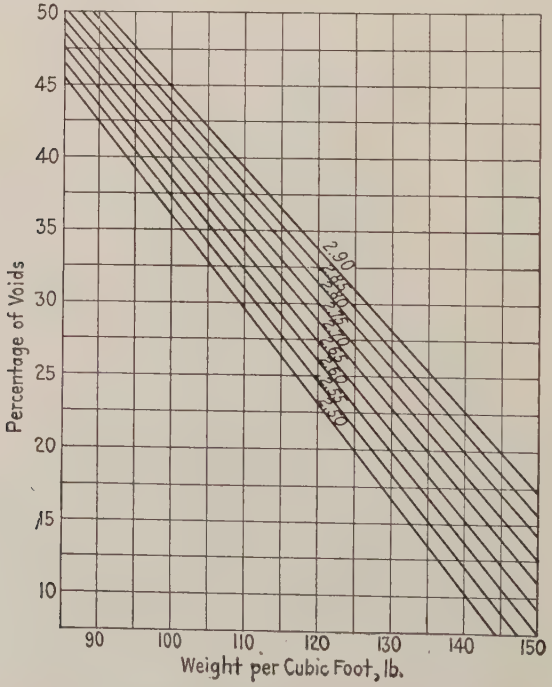


FIG. 97.—Relationship between percentage of voids and weight per cubic foot for specific gravities from 2.50 to 2.90.

Example.—How much concrete will a one-bag batch of 1:2:3 mix concrete produce with a water-cement ratio of 0.8? What are the quantities of materials per cubic yard of concrete? The materials are to be measured by volume and are found to have the following percentages of voids:

Cement	52
Sand	33
Pebbles	40

In a one-bag batch there will be 1 cu. ft. of cement, 2 cu. ft. of sand, 3 cu. ft. of pebbles and 0.8 cu. ft. of water. The volumes of solids and the volume of water are as follows:

Cement	1×0.48	0.48 cu. ft.
Sand	2×0.67	1.34 cu. ft.
Pebbles	3×0.60	1.80 cu. ft.
Water		0.80 cu. ft.
Total		4.42 cu. ft.

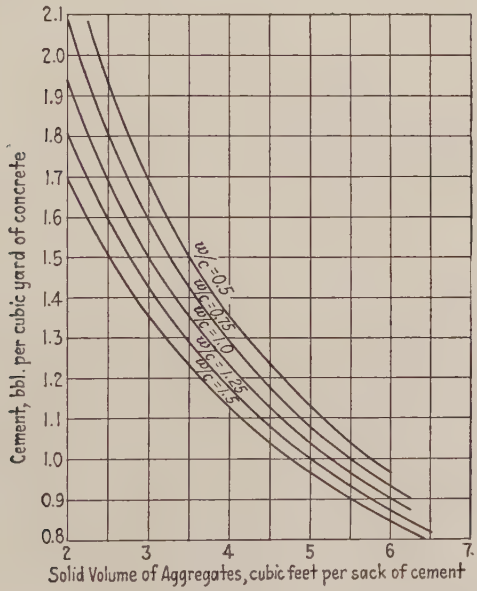


FIG. 98.—Relationship between cement content of concrete and solid volumes of aggregates per sack of cement for various water-cement ratios.

The 6.8 cu. ft. of unmixed materials produce only 4.42 cu. ft. when mixed together. This information is of value in determining the number of batches to mix for a given amount of concrete.

The number of bags (cubic feet) of cement per cubic yard of concrete may be found from the proportion

$$\frac{1 \text{ bag cement}}{4.42 \text{ cu. ft. concrete}} = \frac{x \text{ bags cement}}{27 \text{ cu. ft. concrete}}$$

and is in this case 6.12. The volume of sand is twice that of the cement, or 12.24 cu. ft. The volume of pebbles is three times the volume of cement or 18.36 cu. ft.

The above computations are tabulated in the following table:

	Percentage of voids	Solid volume in one-bag batch	Materials per cubic yard of concrete	
Water	0	0.80	4.90 cu. ft.	36.75 gal.
Cement	52	0.48	6.12 cu. ft.	1.53 bbl.
Sand	33	1.34	12.24 cu. ft.	0.45 cu. yd.
Pebbles	40	1.80	18.36 cu. ft.	0.68 cu. yd.

Formula. A formula for these computations would be

$$\text{Barrels of cement per cubic yard of concrete} = \frac{6.75}{C + A + B + W}$$

in which

6.75 = number of barrels per cubic yard of cement.
C = solid volume of cement in a one-bag batch.
A = solid volume of fine aggregate in a one-bag batch.
B = solid volume of coarse aggregate in a one-bag batch.
W = volume of water in a one-bag batch (does not include the water absorbed by the aggregates).

FULLER'S FORMULA

William B. Fuller developed a formula which is not so accurate as the method described above, but which is easier of application. In Fuller's method no consideration is given to the voids in the materials nor to the amount of water used, items which affect the amount of concrete produced. Because of the ease of application, it has found quite general use in spite of its inaccuracy. The formulas are

$$C = \frac{\text{constant (usually taken as 11)}}{c + s + g}$$

$$S = C \times s \times \frac{3.8}{27}$$

$$G = C \times g \times \frac{3.8}{27}$$

in which

C = number of barrels of cement per cubic yard of concrete.
S = number of cubic yards of fine aggregate per cubic yard of concrete.

G = number of cubic yards of coarse aggregate per cubic yard of concrete.
c = proportion of cement.
s = proportion of fine aggregate.
g = proportion of coarse aggregate.

For well-graded aggregates deduct 5 per cent from the values obtained.

The number of cubic feet of cement in a barrel is taken above as 3.8. At the present time a sack of cement is generally considered to be 1 cu. ft. so that the figure should be 4.0. At the time Fuller prepared the formula the richer mixes were unknown and aggregates were not nearly so well graded. The values for the richer mixes are a little too high.

TABLE 17.—QUANTITIES OF MATERIALS PER CUBIC YARD OF CONCRETE. COMPUTATIONS BASED ON FULLER'S FORMULA

Mix	Cement, barrels	Fine aggregate, cubic yards	Coarse aggregate, cubic yards
1:1½:3	2.00	0.42	0.84
1:2:3	1.83	0.51	0.77
1:2:3½	1.69	0.47	0.83
1:2:4	1.57	0.44	0.88
1:2½:4	1.47	0.51	0.82
1:3:5	1.22	0.51	0.85
1:3:6	1.10	0.46	0.92
1:4:8	0.85	0.48	0.95

For well-graded materials deduct 5 per cent from the above quantities. All materials are to be measured loose.

Example.—What are the quantities of materials per cubic yard of concrete for a 1:2:4 mix?

$$C = \frac{11}{1+2+4} = 1.57 \text{ bbl.}$$

$$S = 1.57 \times 2 \times \frac{3.8}{27} = 0.44 \text{ cu. yd.}$$

$$G = 1.57 \times 4 \times \frac{3.8}{27} = 0.88 \text{ cu. yd.}$$

For well-graded aggregates we would deduct 5 per cent from the values obtained above which would make the cement 1.49, the sand 0.42 cu. yd., and the coarse aggregate 0.84 cu. yd. A 1:2:4 concrete is generally considered to require 6 bags of cement per cubic yard of concrete.

Proportions by Weight

Proportions are normally given by bulk volume of the various materials. In the past few years there has been a slight tendency to weigh the materials rather than to measure by bulk volume. The proportion by volume may be easily changed to one by weight.

Determine the weights per cubic foot for each material, in the condition in which they are to be measured according to the specifications. Cement is generally specified to weigh 94 lb. per cubic foot. Aggregates are usually specified to be measured on a loose and dry basis even though they are never dry as they are used on the job. In addition to the above determination, secure also the percentage of moisture in the aggregates based on the weight of a cubic foot of the loose dry material.

For purposes of illustration, assume that the sand weighs 110 lb. per cubic foot, loose and dry, that it contains 10 lbs. of moisture for each 110 lb. of dry material, that the coarse aggregate weighs 100 lb. per cu. ft., loose and dry, and contains 3 lb. of moisture for each 100 lb. of dry material. Assume also a 1:2:4 concrete by volume. The weights of materials for a one-bag batch using dry materials would be:

Cement	$1 \times 94 = 94$ lb.
Sand	$2 \times 110 = 220$ lb.
Coarse aggregate	$4 \times 100 = 400$ lb.

The proportion by weight is secured by dividing each of the above values by 94 lb. and for the above case is 1:2.34:4.26. If the moisture is added on to the weights for the dry materials the proportion becomes 1:2.55:4.38

If the specifications provide for loose dry volumes as the basis for measurement, it would not be correct to determine the weight per cubic foot of the moist sand and the moisture content and then take the difference as the weight per cubic foot of dry sand. The small amount of moisture present in the fine aggregate will give a bulking action which may increase the bulk volume of the aggregate as much as 30 per cent. The question frequently arises whether moist sand will weigh more per cubic foot than dry sand. The best way to convince oneself

is to fill a small container with both moist and dry sands and to weigh each.

Correcting for Bulked Sand

While it has been known for many years that small amounts of moisture in sand increases the bulk volume, no practical application was made of this information in the measurement of materials for concrete until a few years ago. Even today some engineers specify that the materials shall be measured on a dry basis, but require the contractor to measure out the same number of cubic feet of bulked as is specified for dry sand. Many sands used extensively in concrete work bulk as much as 30 per cent, and occasionally a fine sand is found which will bulk as much as 50 per cent. Unless a correction is made for this bulking the contractor will suffer financially, and harsh mixtures will often result due to undersanding.

What is the resulting effect if no correction is made for bulking on the 1:2:3 mix used in the illustration earlier in this chapter (page 179), and assuming that the percentage of moisture is such as to cause a 20 per cent bulking of the sand? For each sack of cement, 2 cu. ft. of bulked sand is measured out, which is 120 per cent of the dry volume of the sand. The dry volume of the sand is 1.66 cu. ft. and the proportions based on dry materials are 1:1.66:4.

The reduction in quantity of concrete per batch may be roughly estimated from the following: A one-bag batch as previously estimated produces 4.42 cu. ft. of concrete. The only item on which we can estimate the exact change is the sand, which becomes

$$1.66 \times 0.67 = 1.12 \text{ cu. ft.}$$

The water requirements will probably be a little less because of the decrease in aggregate used. Assuming, however, that the water requirements are the same, the amount of concrete produced is estimated to be 4.20 cu. ft., or a reduction of 0.22 cu. ft. below the correct amount. This is approximately 5 per cent. Reduced to money this amounts to approximately 4 to 6 cts. per square yard for 7-in. pavement slab.

Making Correction in the Field.—The following example is given as a method of making the correction for bulking in the field. Quantities may be varied to fit conditions.

A contractor is mixing a five-bag batch of 1:2:3 concrete. The specifications provide that the aggregates shall be measured by volume on a loose dry basis. The sand as used is moist. What is the volume of moist sand which should be measured per batch to give the amount intended in the specifications?

Weigh out 125 lb. of the moist sand as it is being used on the work. Surface dry in the sun or on a stove. Weigh the dry material. Assume this weight to be 120 lb. The percentage of moisture is $4\frac{1}{6}$ per cent based on the dry weight or 4 per cent based on the moist weight.

Using the material which has just been dried determine the weight per cubic foot in a loose condition. This may be done by weighing in the cubic foot box. Assume this weight to be 104 lb. per cubic foot.

Measure out in the regular measuring device a batch of the moist sand. In this case it would be 10 cu. ft. Run the sand into a truck and determine its weight. Assume this to be 900 lb.

Compute the weight of dry sand. It was found above that the percentage of moisture based on the moist sand was 4 per cent. 4 per cent of 900 lb. is 36 lb. The weight of dry sand is 864 lb. The volume of dry sand is $864 \div 104 = 8.30$ cu. ft. The required volume of moist sand then may be found from the proportion

$$\frac{\text{Volume of moist sand to be used}}{10 \text{ cu. ft.}} = \frac{10 \text{ cu. ft.}}{8.30 \text{ cu. ft.}}$$

and the volume is 12.05 cu. ft. The measuring hopper should be set for 12.05 cu. ft. in order to get 10 cu. ft. of sand as intended by the specifications.

Percentages of moisture and weights of batches of sand may be determined from time to time. After the first determination it is not necessary to surface dry 125 lb. of sand. The size of the sample should be at least one hundred times the smallest division on the balance used in the weighings. The variation in moisture from day to day will be small and hence the variations in amounts of sand will also be small.

Problems

General data for following problems:

	Sand, pounds	Crushed limestone, pounds
Weight per cubic foot dry	105	90
Percentage of moisture by weight	6	1
Percentage bulking	20	0

Proportions 1:2½:4 by loose dry volumes water-cement ratio = 1.0.

1. Estimate amount of concrete produced by a one-bag batch of concrete. Figure quantities of materials per cubic yard of concrete. (Give cement in barrels or bags, aggregates in cubic yards and water in gallons.)

2. Estimate quantities of materials using Fuller's formula. (Do not take values from table.)

3. Figure proportions by weight of dry materials.

4. Figure weights of materials for a six-bag batch as they would be used on the job.

5. Compute the volume of bulked moist sand necessary to measure out for a six-bag batch in order to secure proper amount based on dry volumes.

CHAPTER 13

SPECIFICATIONS

Specifications are prepared to describe materials to be furnished or methods to be followed in making or building something. For construction work both the materials to be used and the methods to be followed in putting together the materials are described. Drawings are also made to accompany the specifications showing the dimensions, sizes and locations of various items. The drawings and the specifications should be well coordinated so as to facilitate their use.

American Society for Testing Materials Specifications.—The American Society for Testing Materials has prepared a large number of specifications for various materials used in engineering work and for methods of testing these materials. Those which are labeled *standard* have been through the full process of preparation and have been adopted as standard by the society. Others which are labeled *tentative* are being developed and have not reached the point where they are ready to be adopted as standard. Both the standards and the tentative standards are subject to revision at any time.

Under the heading for each is a *serial designation*, consisting of a letter and a number, and is followed by another number indicating the year of its adoption in that form. The letter T is placed after the year in the case of all tentative standards. The serial designation for the standard for portland cement is C9. The last change was made in 1926. The complete designation is written C9-26.

The A. S. T. M. specifications are used either by reference or by quoting in part or in full. It is quite common, for instance, to say that the portland cement shall meet the requirements of the American Society for Testing Materials as given in their *Standard Specifications and Tests for Portland Cement*, serial designation: C9-26. Some engineers, on the other hand, prefer to include the whole specification verbatim. Frequently only a part of a specification is desired, in which case that portion must be copied.

The A. S. T. M. specifications are part of the copyrighted proceedings of that organization but no effort is made to restrict their use by engineers in preparing specifications.

Some specification writers, in order to be sure that they are using the latest revision of the A. S. T. M. specification, add a clause after the serial designation such as: "or subsequent revisions thereof."

Preparation of Specifications.—Each engineer has his own way of preparing specifications so that comments here can only be of a general nature. General provisions of the contract and definitions should probably come first, to be followed by the requirements for the various materials. Description of the methods of construction should come last and should be arranged in a logical order. The basis of payment for each item should be clearly defined.

It should be kept in mind that the specifications become part of the contract which is later signed by the persons having the work done and by those who are to do it. The contractor in signing the contract agrees to do the work according to the specifications and drawings. In certain states the specifications also become part of an ordinance which is passed by the city council.

Specifications Quoted.—Two sets of specifications for concrete construction are quoted in full. The first set is for part of the Wacker Drive improvement in the city of Chicago and is chosen because of the high quality of concrete secured and because of the publicity which the work has received.[1] The other set is that of the Illinois Division of Highways. It is chosen because of the extensive program of concrete highway development in progress in that state. The division has always carried on extensive research work in concrete in order to keep themselves well informed.

The A. S. T. M. specifications for cement and aggregates are given in the chapters discussing these materials.

[1] LORD, A. R. "Notes on Wacker Drive," *Proc. Am. Concrete Inst.*, 1927.

Concrete Specifications for Sub and Superstructure of Section Number 9 of the South Water Street Improvement[1] in the City of Chicago, Illinois

Part 5. Materials

Concrete Materials for Structural Concrete

Definition.—"Structural Concrete" shall be understood to mean all concrete in walls, piers, footings, columns, girders, beams and slabs, etc., excepting only concrete in pavement foundations and in sidewalks, curbs, and gutters laid on the ground.

Portland Cement.—Portland cement shall meet the requirements of the Standard specifications for portland cement of the American Society for Testing Materials (Serial Designation: C9-21) with the additional requirement that the average tensile strength of standard mortar at 28 days shall be at least 20 per cent higher than the strength at 7 days.

No brand of cement shall be used, the record of which on actual construction work under conditions similar to those on this work is not such as to assure the Board of Local Improvements that it will give as satisfactory results as any other brand that may be readily obtained for the work.

Reground Cement.—Reground cement for sidewalk light frames shall be portland cement as specified, but reground to such fineness that 95 per cent will pass a No. 200 standard sieve.

Hydrated Lime.—Hydrated lime shall meet the requirements of the tentative specifications for hydrated lime for structural purposes of the American Society for Testing Materials (Serial Designation: C6-23T).

Fine Aggregate.—Fine aggregate shall consist of sand having clean, hard, strong, durable, uncoated grains and free from injurious organic matter, loam, amounts of dust, lumps, soft or flaky particles, shale, alkali, or other deleterious substances.

Fine aggregate shall range in size from fine to coarse particles within the limits indicated in the following table:

Item	Percentage by Weight
Passing through No. 4 sieve, not less than	85
Passing through No. 50 sieve, not more than	30
Passing through No. 50 sieve, not less than	10
Weight removed by decantation, not more than	3
Passing through No. 100 sieve, not over	2

[1] It is known as Wacker Drive now.

The sieves and method of making sieve analysis shall conform to the "Standard Method of Test for Sieve Analysis of Aggregates for Concrete" (Serial Designation: C41-24) of the American Society for Testing Materials.

The decantation test shall be made in accordance with the "Tentative Method of Decantation Test for Sand and Other Fine Aggregates"

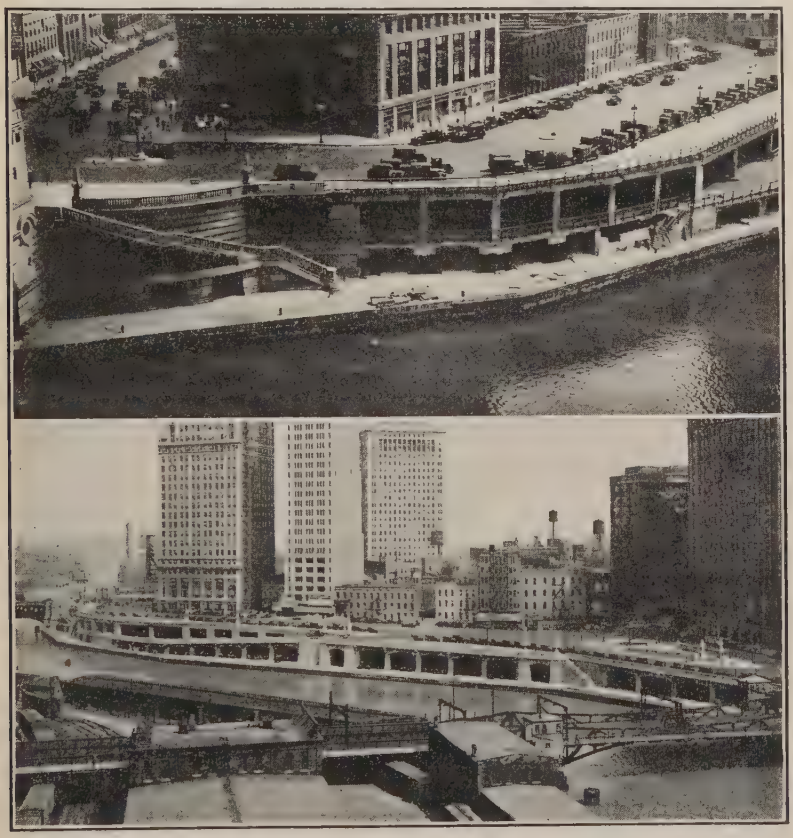


FIG. 99.—Views of the completed Wacker Drive (completed, 1927).

(Serial Designation: D136-22T) of the American Society for Testing Materials.

Fine aggregate shall be of such quality that mortar briquets, cylinders, or prisms, consisting of one part by weight of portland cement and three parts by weight of fine aggregate, mixed and tested in accordance with the methods described in the "Standard Specifications and Tests for Portland Cement" (Serial Designation: C9-21) of the American Society for Testing Materials will show a tensile or compressive strength

at ages of 7 and 28 days of not less than 100 per cent of that of 1:3 standard Ottawa sand mortar for the same water-cement ratio made with the same cement. Concrete tests shall be made in accordance with the "Tentative Methods of Making Compression Tests of Concrete" (Serial Designation: C39-21T) of the American Society for Testing Materials.

Sand when tested in accordance with the "Standard Method of Test for Organic Impurities in Sand for Concrete" (Serial Designation: C40-22) of the American Society for Testing Materials shall show a color not darker than the standard color.

Coarse Aggregate.—Coarse aggregates shall consist of crushed stone, washed gravel, or other approved inert materials with similar characteristics or combinations thereof, having clean, hard, strong, durable, uncoated particles free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter. Coarse aggregate used in concrete for the viaduct structure shall be crushed stone.

Coarse aggregate shall range in size from fine to coarse particles within the limits stated in the following table:

Coarse aggregate, designation	Percentage by weight passing through standard sieves with square openings				
	3 inch	1½ inch	¾ inch	⅜ inch	No. 4
No. 1				Minimum 95	Maximum 5
No. 2			Minimum 90	20 to 40	Maximum 5
No. 3		Minimum 95	20 to 40		Maximum 5

The test for size and grading of aggregate shall be made in accordance with the "Standard Method of Test for Sieve Analysis of Aggregates for Concrete" (Serial Designation: C41-24) of the American Society for Testing Materials.

Source of Materials.—The various concrete materials shall be taken from sources which are adequate to supply the entire requirements of this section of the Improvement without delaying the work. No change will be permitted in the brand of cement or in the source and character of the fine and coarse aggregate, after the concrete proportions have been determined. The engineer shall be notified of the source from which all aggregates will be taken for all superstructure concrete at least 3 weeks before such concrete will be needed, to permit of sampling, analysis and 7 day tests of concrete strength. This requirement must be strictly enforced in order to maintain uniformity in the concrete.

Adequate storage facilities must be provided at the source of fine and coarse aggregates to insure (1) that no freshly washed or dredged material shall be delivered to the job without opportunity to drain for

at least one week; and (2) that the supply of aggregate may be maintained in the necessary volume at all times, including the winter season.

FIG. 100.—Construction views on Wacker Drive improvement, Chicago, Ill.

The moisture content in the coarse aggregate shall not be greater than that commonly present in pits and in no case shall it exceed 2½ per cent by weight.

Granite Screenings.—The fine aggregate for mortar to be used for surface finish of sidewalks, loading platforms, curbs, stairs, etc., shall consist of granite screenings free from dust, loam clay and other deleterious matter and so graded that 95 per cent will pass a screen having ¼-in. diameter holes, that not more than 20 per cent will pass a No. 50 standard sieve, and that 95 per cent will be retained on a No. 80 standard sieve.

Water.—Water for concrete shall be clean and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.

Part 7. Field Work

General

Storing of Materials.—Materials, when delivered, shall be stored as the Board of Local Improvements may direct and in such a manner that they will not unnecessarily hinder the work of other contractors on the improvement or be an obstruction to traffic. This also applies to temporary buildings or sheds for the storage of materials, tools, and equipment.

Facilities shall be provided on the job for the storage of cement and lime in such a manner that they are at all times protected from moisture, and any material which shows caking or lumping shall be rejected and removed from the work. This protection from moisture shall extend to the transportation of the cement from the mill to the work, the trucks used for this purpose being provided with waterproof covers.

Aggregate to be used for making concrete shall be stored in bins or boxes in such a manner as to avoid admixture of dirt or other foreign matter. It shall be protected from the direct rays of the sun in hot weather (maximum temperature over 75°F.) and the coarse aggregate shall be protected from rain in order to maintain uniform moisture conditions.

Trucks or wagons used to haul aggregate to the site of the work shall be clean and free from straw, dirt, or debris left from previous usage. Each size and kind of aggregate shall have a separate and distinct place of storage and no mixture of different coarse aggregates shall be used in this work.

If steam is introduced into the coarse aggregate to heat the same in winter suitable gutters shall be provided to carry away the excess water and prevent the same from running into the mixer.

Materials shall not be stored on the finished structure without permission from the Board of Local Improvements and in no event shall the load on the structure exceed the load for which it is designed.

Concrete Work

General.—All concrete work shall conform to the following specifications except that detailed requirements specified for certain classes of work or certain portions of the structure shall take precedence over these general specifications.

Concrete Mixture.—Except as specified under *Concreting in Cold Weather* the concrete for the various parts of the work shall be mixed in accordance with the following table using the kind of coarse aggregate as specified for the various portions elsewhere in these specifications or on the drawings. Coarse aggregate No. 2 shall be used for all concrete work having one or more exposed faces for which a mortar finish is not specified.

Designation of mixture	Parts by volume			Water, gallons per sack	Part of structure
	Cement	Aggregate			
		Fine[1]	Coarse[1]		
1:7½	1	2.5	5	7.5	Cylindrical piers as specified
1:6	1	2	4	7	Structural concrete work in general
1:4½	1	1.5	3	6.5	Columns and column capitals of viaduct structure

[1] In these two columns are stated the usual nominal proportions. The exact division of the total aggregate between the fine and coarse will be determined by the Board of Local Improvements so as to produce the required strength and density. The volume of sand may be increased as much as 30 per cent depending on the character of aggregate furnished for the work, but such increase in fine aggregate shall be balanced by an equal reduction in volume of coarse aggregate.

1:6 concrete shall be used for any portion of the work for which the contract drawings and specifications do not give the mixture of concrete. In case of conflict the richer mixture shall be used.

The amount of water given in the table is inclusive of the moisture in the aggregate. The Contractor may increase the water content of any mix at his own expense provided that the water-cement ratio shall be maintained constant and provided other requirements of these specifications are met.

Hydrated Lime.—Hydrated lime shall be incorporated in all concrete for reinforced concrete work such as columns, girders, brackets, beams,

slabs, foundation girders, and all concrete used for encasement but shall not be used for mass concrete such as cylindrical piers, retaining walls, and dock walls where the reinforcement is of secondary importance.

Whenever used, hydrated lime shall be added in the proportion of 8 pounds of hydrated lime to 1 sack of cement.

Where hydrated lime is used the proportion of cement and fine and coarse aggregate shall not be altered but the hydrated lime shall be used as an additional ingredient.

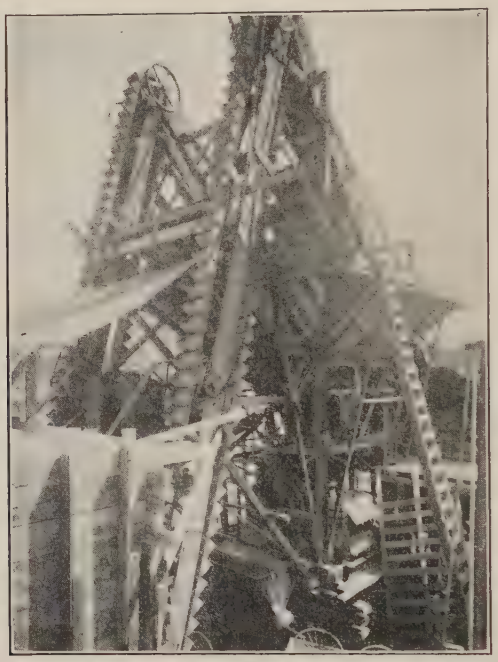


FIG. 101.—A mixing plant on the Wacker Drive improvement.

Proportioning.—The unit of measure shall be the cubic foot. A bag containing not less than 94 lb. of cement shall be assumed as 1 cu. ft. of cement. Fine aggregate shall be measured in an inundated condition by means of the "Inundator" or some fully equivalent device. Coarse aggregate shall be measured in an approved stone batcher. Water in excess of that in the inundated sand shall be measured in a batch tank. All measuring devices shall be calibrated so that the contents in cubic feet at any setting may be readily determined. The Contractor shall supply necessary labor and material for checking the

volume of material as delivered by the measuring devices at such times as directed by the Board of Local Improvements.

The precise proportion between fine and coarse aggregate to be used where any mix is designated on the plans or in these specifications shall be determined by the Board of Local Improvements on the basis of tests of the materials furnished by the Contractor for use on the work. The Contractor shall supply the Board of Local Improvements with sufficient material of each kind for such tests of proportions, density, and strength as it may find it desirable to make and shall transport such material to the testing laboratory. Sampling shall be done by the Board of Local Improvements. Such material shall be furnished 3 weeks in advance of the time when construction work is to start on the superstructure concrete and at least 2 weeks in advance of the construction work on substructure concrete.

Machine Mixing.—All concrete shall be mixed by machine except in special cases where the Board of Local Improvements may permit mixing by hand. A machine mixer equipped with a proper water measuring device and a lock timing device, approved by the Board of Local Improvements, and of the batch type shall be used. The mixer shall be so constructed and so operated that the product delivered will be of the specified proportion and consistency and thoroughly mixed. Where hydrated lime is used it shall be added to each batch in the proper proportion and mixed in the regular manner. After all materials for a batch are in the drum, the mixing shall be started and shall be continued for at least 1½ min. before any part of the batch is discharged from the drum. The drum shall be completely emptied before receiving material for the succeeding batch. The drum shall revolve at a rate of not less than 12 nor more than 16 r.p.m. The size of the batch shall not exceed the manufacturer's rated capacity of the drum.

Hand Mixing.—Hand mixing may be used for minor portions of the work, after permission is obtained from the Board of Local Improvements. It shall be done on a water-tight platform of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed ½ cu. yd. each. The mixing shall be done as follows: The fine aggregate shall be spread evenly on the platform, the cement and hydrated lime shall be spread evenly on the fine aggregate and these ingredients shall then be mixed thoroughly until of an even color. The water necessary to mix the mortar shall then be added and the mortar spread again. The coarse aggregate, which if dry shall be thoroughly wetted, shall then be added to the mortar and the mass turned over with shovels or hoes until thoroughly mixed and the coarse aggregate thoroughly covered with mortar.

No mixing shall be done on or over new concrete work unless the same is thoroughly covered and protected from damage.

Consistency.—The consistency of concrete shall be controlled by the measurement of the slump of freshly mixed concrete. In general, the slump shall be maintained between 3 and 4 in., except that occasional batches with slumps greater than this may be permitted where the concrete appears too dry (as in hot weather) or where special difficulty in placing exists (as in heavily reinforced beams or under expansion joint plates). Where water rises to the surface batches shall be made drier until this water disappears.

Retempering.—Retempering of mortar or concrete, that is, remixing with water after it has partially set, will not be permitted.

Forms.—Forms shall be built and put together by skilled mechanics. They shall be built to exact lines in accordance with the drawings and in such a manner that the best possible concrete finish will be obtained without any special treatment of the forms and without extensive patching of the concrete after the forms have been stripped. They shall be tight so as to prevent loss of mortar and shall be well braced and tied together so as to prevent bulging or distortion during the progress of concreting. All form lumber shall be tongued and grooved. Forms shall be kept damp at all times after being laid to prevent shrinking and opening of cracks.

The ties or clamps used shall be of the detachable type which will permit the tying together of the forms in such a manner that no nails or wires will be exposed in the face of the concrete when the forms are stripped.

Removable sections shall be left in the forms wherever necessary to facilitate cleaning.

Forms and form lumber shall be carefully cleaned and inspected before using again.

The Contractor shall be fully responsible for the stripping of forms and removal of supports but such work shall not be done against the instructions of the Board of Local Improvements.

All excavations for footings or other concrete structures, if so ordered, shall be paved with planking, concrete, or a layer of crushed stone carefully leveled or shaped to conform to the underside of the footing or structure.

Placing of Concrete.—Concrete, after the completion of the mixing, shall be brought to the place of final deposit without loss of time and under no circumstances shall concrete be used that has partially set before being placed in the forms.

The concrete shall be deposited so as to prevent the separation of the ingredients and so as to insure thorough compacting. Concrete placed in forms shall be compacted by working with a straight shovel or slicing tool kept moving up and down until the ingredients have settled in their proper place. During this operation the coarse aggregate shall

be forced away from the forms for exposed work so as to make a ½-in. thick mortar facing next to the forms. All concrete must be deposited in layers of uniform thickness throughout, except in horizontal slabs and beams. Inasmuch as the superstructure concrete will be exposed to the weather at all times an exceptional amount of puddling shall be done, to produce dense concrete throughout the structure.

In the case of beams or girders with closely spaced steel near the upper surface concreting shall be done from either side and concrete shall not in any case be deposited on top of such top steel until the beam is completely filled and thoroughly puddled up to the under surface of such top steel. The top of the roadway slab shall be finished off with a ½-in. layer of mortar to a reasonably smooth surface.

Before placing concrete in columns the forms shall be filled with mortar (of the same materials and proportion as the mortar in the concrete) to a depth of 6 in. Before placing concrete in beams or girders the forms shall be filled with mortar in the same manner to a depth of from 1 to 2 in. as may be directed and depending on the congestion of reinforcing bars in the beam. A half-inch layer of mortar shall be placed in the bottom of the deck slab forms.

Concrete shall not be deposited under water without the express approval of the Board of Local Improvements. When such approval is given, the concrete must be so handled as to prevent the washing of the cement from the mixture.

Before depositing concrete in the forms, they shall be thoroughly oiled with paraffin oil, and the space to be filled with concrete shall be thoroughly cleaned of all dirt and rubbish.

Whenever the placing of concrete is to be suspended for a period of more than 3 hours' time, the top surface of the concrete then in place shall be trenched or roughened to provide a bond with the next succeeding layer of concrete to be placed thereon. The provisions for bonding successive courses of concrete shall, at all times, be subject to the direction of the Board of Local Improvements.

Before placing new concrete on or against concrete which has set, the surface of the latter shall be thoroughly cleaned of scum, laitance and foreign material, and shall be roughened, wetted down and slushed with neat portland cement grout.

Chutes may be used to convey the concrete to a hopper on the formwork but the final deposition of the concrete in the forms shall be from concrete carts.

Concreting in Cold Weather.—For all superstructure work, including deck slab and columns, exposed vent ducts and loading platforms and reinforced concrete walls (including the dock walls), extra cement shall be provided and the amount of mixing water (including moisture

in aggregates) reduced and the length of mixing time increased in accordance with the following table:

For concrete placed during months of:	Total cement per cubic yard 1:6 concrete, sacks	Mixing water per sack of cement, gallons	Time of mixing, minutes
October and April	7	6.6	1½
November and March	8	6.2	1¾
December, January and February	9	5.8	2

The cement and water contents and the time of mixing for 1:4½ concrete shall be changed proportionately.

During the months November to March, inclusive, all materials shall be heated before being introduced into the mixer to insure a temperature of the fresh concrete of not less then 80°F. During the months of November and March the concrete shall be protected from falling below a temperature of 50°F. at any time during the first 14 days after placing. All concrete placed during the months of December, January and February shall be protected for 14 days after placing in such a manner as to maintain a temperature of not less than 60°F. at all times during the first 7 days after placing and a temperature of not less than 50°F. for the second 7 days.

Under special permission from the Board of Local Improvements concrete may be laid in freezing weather, provided the following rules are strictly complied with:

1. The initial temperature of the concrete after having been put in place in freezing weather, shall not be less than 80°F. The air temperature about the concrete shall be maintained at not less than 60°F. for at least 7 days and nights.

2. The concrete so laid must be covered and protected from freezing temperature as soon as completed. This protection shall be such as to provide an enclosure above and on the sides of the new concrete as well as below.

3. To obtain concrete of the required initial temperature of 80°F., the materials used in mixing the concrete shall be heated as follows:

a. The water shall be heated to at least 90°F. with the temperature near freezing, and approximately three degrees higher for each degree the temperature shall be below 30°F.

b. The sand and usually the stone shall be heated. Great care must be taken to heat the mass evenly. Heat should range from 90°F.

with the temperature at freezing to not above 150°F. in the coldest weather. Coarse aggregate shall not be wetted in heating.

4. Temperature shall be measured with a standard thermometer.

5. No hydrated lime shall be used in concrete permitted to be placed in freezing weather, nor shall salt, calcium chloride, or any other chemical be added.

6. During the course of construction, incompleted courses or sections of concrete work must be protected from freezing during the intervals between placing batches of concrete.

7. In the event that concrete is damaged by frost, the damaged mass must be removed to sound concrete and replaced by fresh concrete at the expense of the contractor.

Surface Finishes. *Spaded Finish.*—All exposed work not requiring decorative treatment and for which a wearing surface is not specified shall be given a spaded finish as described above. Great care shall be exercised to prevent the formation of air pockets and voids in the surface. After the removal of the forms all voids which may appear on the surface shall be filled with a mortar of the same proportions of cement and sand as that of the concrete, and rubbed smooth and even with the surface with a wooden float. A trowel shall not be used for this purpose. The board marks of the formwork shall be restored on such patches. All patches shall be kept damp for at least 7 days.

The cost of spaded finish shall be merged into the contract price for concrete.

Wearing Surface.—The exposed portions of sidewalks, stair treads, curbs, gutters and vent ducts, and the top of the dock wall shall be covered with a wearing surface consisting of portland cement mortar mixed in the proportion of 2:3, using granite screenings. Not more than 4 hours shall elapse between the time of concreting the base of such work and the application of the wearing surface. The wearing surface shall be spread in such a manner as to insure a smooth and even surface after being thoroughly troweled. Sidewalks, curbs, gutters, and stair treads shall be given a wearing surface of ¾ in. in thickness. The top of the combined vent duct and loading platform and of the dock wall shall have a wearing surface of one inch in thickness.

If more than 4 hours shall elapse before placing the wearing surface a neat cement wash shall be applied to the surface of the concrete before placing the wearing surface thereon.

Rubbed Finish.—All concrete work which enters into the ornamental treatment of the viaduct structure shall have a special rubbed finish as hereinafter described.

Included hereunder shall be the entire river front of the viaduct structure including the returns and the back face of the arches and

piers but not the columns or half columns which project from the piers towards the lower level roadway.

Where the ornamental facing occurs at the lower side of the forms such as the fluted architectural facing below the cornice on the river front of the viaduct, 1:2 portland cement mortar shall be poured into the form for a depth sufficient to cover the ornamental work and prevent the stone aggregate from working to the face of the forms.

The coarse aggregate shall be carefully worked back from the forms into the mass of the concrete with spades, fine stone forks, or other suitable tools, so as to bring a surface of mortar against the form. Care shall be taken to remove air pockets and prevent voids in the surface.

The forms shall be removed from the surfaces to be finished, as early as practicable, and with great care. All joint marks, projections. and inequalities shall then be chipped off and all voids filled with a mortar of the same proportion of cement and sand as that of the concrete. The surface shall then be thoroughly wetted with water and while wet, rubbed to a smooth, uniform finish with a brick made of 1 part portland cement and 2 or 2½ parts sand; or with a No. 3 Carborundum brick followed by a No. 30, or with a No. 24 Carborundum brick, as may be necessary to obtain the desired degree of smoothness.

No mortar or cement shall be applied except to fill distinct voids in the surface. Uneven places shall be smoothed by rubbing down and not by plastering. The surface shall be kept moist and protected from rapid drying for not less than 3 days.

Protection.—All new concrete work shall be protected against drying out and kept moist for from 7 to 14 days as conditions permit. The surface of the viaduct slab and other horizontal surfaces shall be covered with sand at least 1 in. thick which shall be applied as soon as the concrete is hard enough to walk on and sprinkled as often as necessary to keep it moist at all times. Vertical or steeply inclined surfaces shall be sprinkled at least twice daily and oftener on hot days.

In winter live steam may be used for heating and dampening the concrete, in which case no other provision for dampening need be made. Where salamander or other dry heat is applied to fresh concrete, special measures shall be taken to keep the concrete moist at all times.

Tests of Concrete.—The Board of Local Improvements will conduct two series of tests to determine the quality of concrete in the work.

The first concrete tests will be started as soon as the contract is awarded. Test specimens will be made in advance of the construction work and the Contractor shall furnish representative samples of the materials to be later used in the work.

The second series of test specimens will be taken from concrete deposited in the forms and tested to determine the strength of concrete as actually placed in the work.

Specification Illinois Division of Highways[1]

Materials

Portland Cement.—The cement shall be some standard brand of portland cement which has been in practical use in public work and has given satisfactory results therein. No brand of cement shall be used which the engineer deems unfit for the work. The cement shall meet the requirements of the *Tentative Standard Methods of Sampling and Testing Highway Materials* as adopted by the American Association of State Highway Officials, 1922, with subsequent revisions.

Storage.—The contractor shall provide suitable means for storing and protecting the cement against dampness. When cement is furnished by the state, any that has been damaged because of the failure of the contractor to provide suitable storage shall be paid for by the contractor.[2] Different brands or grades of cement must be stored separately.

Damaged Cement.—Bags of cement which, for any reason, have become partially set or which contain lumps of caked cement shall be rejected.

Mixing Different Cements.—Different cements, even if tested and approved, shall not be mixed during use, nor used alternately in any one class of construction.

Transportation of Cement.—In transporting the cement it shall be kept in a weather-proof compartment, separate from the other aggregates, or placed between the fine and coarse aggregates, or covered with a tarpaulin if placed on top of the batch. If placed in contact with the fine or coarse aggregates, the entire batch of materials shall be placed in the mixer and mixed before the expiration of a period of five (5) hours.

Fine Aggregate.—The fine aggregate shall consist of clean, hard, durable, uncoated stone particles, preferably of a siliceous nature, free from lumps of clay, soft or flaky particles, and organic matter. This description of fine aggregate shall not be interpreted as admitting the use of stone or slag screenings, unless the use of the same has been approved by the engineer in writing.

Impurities.—Fine aggregate containing appreciable quantities of mica, shale, slate, ochre, or other soft grains shall not be used. It shall not contain more than two (2) per cent of material which may be removed by the elutriation test. In no case shall fine aggregate containing lumps of frozen material be used.

Gradation.—The fine aggregate shall be well graded from coarse to fine, and when tested by means of laboratory sieves shall meet the following requirements:

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[1] Used during the construction season of 1928.

[2] The state of Illinois buys the cement and furnishes it to the contractors.

	Per Cent
Passing ¼-in. sieve	not less than 95
Passing 20-mesh sieve	35 to 70
Passing 50-mesh sieve	not more than 20
Passing 100-mesh sieve	not more than 5

Mortar Strength Test.—When the fine aggregate is mixed with portland cement in the proportions of one (1) part of cement to three (3) parts of fine aggregate, by weight, according to standard methods of making 1 to 3 mortar-test specimens, the resulting mortar at the ages of seven (7) and twenty-eight (28) days shall have a tensile or compressive strength of at least 100 per cent of that developed, in the same time, by mortar of the same proportions and consistency, made of the same cement and standard Ottawa sand. Preliminary acceptance samples shall be subjected to both 7- and 28-day tests, and acceptance based thereupon.

Coarse Aggregate.—The broken stone or gravel for coarse aggregate shall consist of clean, hard, tough, durable stone. It shall be free from soft, thin, elongated, or laminated pieces, disintegrated stone, vegetable, or other deleterious matter. In no case shall coarse aggregate containing lumps of frozen or partly cemented material be used.

Crushed Stone.—When crushed stone is used it shall be obtained from rock of uniform quality, having a per cent of wear of not more than 7.

Gravel.—Gravel used for coarse aggregate shall show high resistance to abrasion, and no gravel which, in the opinion of the engineer, does not show wearing qualities at least equal to crushed stone having a per cent of wear of 7 shall be used.

Grading.—All coarse aggregate shall be well graded, and when tested by means of laboratory sieves shall meet the following requirements:

	Per Cent
Passing 2-in sieve	100
Passing 1-in. sieve	not less than 50
Passing ½-in. sieve	not more than 30
Passing ¼-in. sieve	not more than 5

Gradation of Aggregate.—In case the concrete resulting from a mixture of coarse and fine aggregates, which otherwise comply with the provisions of the foregoing sections for fine and coarse aggregates, is not of a workable character, or, when finished does not exhibit a proper surface, as may occur when a fine aggregate having approximately the minimum permitted percentage passing a 20-mesh sieve is used with a coarse aggregate having the maximum permitted percentage passing the ½-in. sieve, the engineer shall, at his discretion, require that (*a*) either a fine aggregate having a greater percentage passing the twenty-mesh sieve; or (*b*) a coarse aggregate having a smaller percentage passing the ½-in sieve, be used.

Unscreened Material.—The use of pit-run or unscreened material, or material made up of a mixture of fine and coarse aggregates contained therein, will not be permitted.

Water.—The water used in mixing the portland cement concrete shall be reasonably clean and free from oil and organic matter. It shall not be brackish or have an acid or alkaline reaction.

Calcium Chloride.—The calcium chloride used for the curing or hardening of concrete shall be in the form of loose dry lumps or flakes, and fine enough to feed readily through the common forms of spreaders used in road work, and when tested by means of laboratory sieves shall meet the following requirements:

	Per Cent
Passing $\frac{3}{8}$-in. sieve	100
Retained on $\frac{1}{4}$-in. sieve....not more than	20
Passing 20-mesh sieve....not more than	10

Chemical Composition.—Ten grams of the material dissolved in 100 cc. of boiling water shall show less than 1.0 per cent insoluble residue. Not more than 1.0 cc. of normal acid shall be required to neutralize the alkalinity of the filtrate, using methyl orange. The chemical composition shall conform to the following requirements:

	Per Cent
$CaCl_2$ (anhydrous)....not less than	73
$MgCl_2$....not more than	0.5
NaCl....not more than	1

The percentage of calcium chloride shall be calculated from the percentage of calcium in the filtrate above referred to, after making a deduction for the SO_4, which shall be assumed to be in combination as $CaSO_4$.

Size of Package.—The calcium chloride shall be delivered in air-tight, moisture-proof bags or sacks containing approximately 100 lb. each, or in air-tight steel drums weighing not more than 350 lb. each. The name of the manufacturer, the lot number, the approximate new weight, and the percentage of calcium chloride guaranteed by the manufacturer shall be plainly marked on each container.

Rejection.—Calcium chloride will be rejected if it fails to pass any of the requirements of these specifications and if it has become caked or sticky in the containers before opening.

Construction

Storage of Aggregates.—If materials are stockpiled, such piles shall be built up in layers not to exceed more than 3 ft. in height and each layer shall be completely in place before beginning on the next. Coning

or building up of stockpiles by depositing material in one place will not be permitted.

Mixing of stone in one storage pile, or alternating batches of different aggregates will not be permitted.

Placing of Aggregates.—The placing of loads or piles of fine or coarse aggregate directly upon the subgrade, or upon the shoulders immediately adjacent thereto, to be wheeled, shoveled, or conveyed directly to the mixer will not be permitted.

The placing of storage piles at intervals of not less than 500 ft. at specially prepared places along the road, preferably at intersecting roads or on private property, will be permitted. Such storage piles shall be at least 6 ft. in height.

If the materials become mixed with earth or other foreign matter between the time of loading at the plant and the time of charging the mixer, they shall be thoroughly cleaned, as directed by the engineer. If not so cleaned, they will be rejected.

Measurement of Aggregates.—The quantities of aggregates for each batch shall be exactly sufficient for one or more sacks of cement; no batch shall be run requiring fractional sacks of cement. All aggregates shall be measured by use of approved automatic measuring devices. No other means of measurement will be permitted.

Side Forms.—The side forms for the concrete pavement shall be of steel. They shall be of sufficient strength that when tested as a simple beam with a load equal to the weight of the finishing machine used, they shall not deflect to exceed ¼ in. in 10 ft. They shall be straight and of a width equal to the thickness of the pavement at the edge. All forms shall be set with exactness to the required grade and alignment of the pavement and be supported in such position, during the entire operation of tamping and finishing, that they shall not at any time deflect as much as ¼ in. from a straightedge 10 ft. in length. The use of bent, twisted, or worn out side forms will not be permitted. All steel forms shall be cleaned and oiled after each time used. If, after forms have been set and before concrete is placed, the subgrade becomes soft and yielding due to rain or similar causes, the forms shall, when required by the engineer, be relaid on a stable foundation.

The contractor shall at all times have on the job sufficient forms to comply with the requirements of subgrade operations specified in Secs. 1–11 and sufficient forms so that it will not be necessary to remove them within 12 hours after the concrete is placed.

Proportions for Concrete.—The concrete for the pavement shall consist of 1 part cement, 2 parts of fine aggregate, and 3½ parts of coarse aggregate. The aggregate shall be placed in the mixer in such a manner as to insure that a uniform amount of each class of aggregate and cement is used in each batch of concrete. One sack of cement

shall be considered as having a volume of 0.95 cu. ft., and all measurements shall be made by volume.

(*a*) *Checking Amount of Concrete Placed.*—The engineer shall calculate the amount of mixed concrete required for any unit of pavement length according to the specifications and the accompanying plans and cross sections.

To determine the amount of cement, fine aggregate, and coarse aggregate required per cubic yard of mixed concrete, the engineer shall make tests as are necessary. This determination shall be made by mixing concrete under actual field conditions.

As often as the engineer deems necessary, this test shall be repeated and new quantities determined.

If, for any such unit of pavement length, the actual amount of cement used exceeds by more than 4 per cent the calculated quantity, determined as above specified, the contractor shall be charged for such excess.

Consistency.—The amount of water used shall be such that the consistency of all batches will be uniform. A consistency in which there is any tendency towards a segregation of the aggregates will not be permitted.

The consistency of the concrete under a visual examination shall conform to the following:

The batch of concrete when deposited upon the subgrade shall tend to settle slowly. The concrete at the edges of the batch shall have a tendency to roll rather than to run. As the batch settles, the individual pieces of aggregate, which should be thoroughly coated with mortar, should crack or break away from adjoining pieces of aggregate. The concrete should be of such a consistency that there will be no glistening of the mortar from an excess of water.

The consistency of the concrete shall be determined by the following test:

A frustum of a cone, 4 and 8 in. in diameter, top and bottom, respectively, and 12 in. in height, shall be placed on its base and filled with concrete which shall be tamped until all voids are filled and a slight film of mortar appears on the surface. The cone shall then be slowly removed and the vertical settlement or "slump" of the concrete noted. This settlement shall not exceed 2 in. nor shall it be less than ½ in.

Mixing Concrete.—Concrete shall be mixed in a batch mixer of a type approved by the engineer. No mixer shall be used which requires less than four sacks of cement per batch.

The mixer shall be equipped with an attachment for automatically timing each batch of concrete so that all the materials will be mixed together for the minimum time required. The timing device shall consist of an automatic arrangement for locking the discharge chute and a device which will warn the operator when all the materials have

been mixed together for the required period. If the timing or locking device becomes broken or fails to operate, the contractor shall immediately place before the mixer operator a clock or watch having a second hand. If the timing or locking device is not repaired or made effective within 3 days from the time it became unserviceable, the mixer shall be shut down until the proper repairs are made.

The type of mixer shall insure uniform distribution of the materials throughout the mass until it is uniform in color and smooth in appearance. All of the materials for each batch of concrete, including the water, shall be mixed at least 1 min. while the drum revolves at the speed for which it was designed, but between 14 and 20 revolutions per minute. If a thorough mixing of the concrete, in the opinion of the engineer, is not effected by this process, a sufficient number of additional revolutions at the same rate shall be given until a thorough mixing of each batch of concrete is secured. Any concrete mixed less than 1 min., as specified herein, shall be dumped outside of the forms and removed from the roadway at the entire expense of the contractor. The volume of material mixed per batch shall not exceed the manufacturer's rated capacity of the drum.

The use of mixers having a chute delivery will not be permitted.

No materials for a batch of concrete shall be placed in the drum of the mixer until all of the previous batch has been discharged therefrom. Water shall be added at the time the materials are being run into the mixer.

(*a*) *Central Mixing Plants.*—The use of a central mixing plant and the transportation of mixed concrete to the road will be permitted, provided there is no unreasonable segregation of the concrete when it arrives at the point where it is to be deposited on the road, and provided further that the period of time elapsing from the time the concrete is mixed until it is deposited on the road does not exceed 30 min. The concrete shall be thoroughly rehandled with shovels or other suitable means, if necessary, to obtain a uniform consistency before tamping. Where proportioned aggregates or mixed concrete are transported to the road by trucks or wagons, the gross weight which will be permitted on the subgrade through any two wheels on the same axle of the vehicle shall not exceed 550 lb. per inch of width of tire upon such wheels, except by written permission of the engineer. The gross weight shall include the weight of the vehicle plus the load upon the vehicle.

(*b*) *Retempering.*—Mortar or concrete which has partially set shall not be retempered by mixing the mortar or concrete with additional materials or water.

Longitudinal Center Joint.—When required by the plans, the concrete pavement shall be built so as to have a longitudinal joint in the center of the pavement. The joint shall be made by installing a specially

designed metal strip which will separate the concrete. The metal strip shall be of the gauge and form specified and indicated on the plans and may be either painted or galvanized. The strips shall be held rigidly in place by suitable pins at least 15 in. long driven vertically through punched holes in the joint. Adjoining strips shall be lapped at least 2 in. and also securely fastened by means of the pins driven through matched holes in the splice. The spacing of the holes and the pins shall in no case be greater than the dimensions shown on the plans. The metal strips shall be not less than 10 ft. and not more than 15 ft. in length. Riveted lengths of metal strip may be used only upon written approval of the engineer. Punched or cut holes shall be provided in the metal strip, spaced as shown on the plans, to receive the transverse bars across the center joint. A templet, approved by the engineer, shall be used to place the metal center joint in horizontal and vertical alignment before depositing and finishing the concrete and care must be taken not to displace the joint material during the finishing operations.

(*a*) *Transverse Reinforcing Steel across Center Joint.*—Transverse round deformed bars of the length, size, and spacing as shown on the plans shall be placed through the center joint. The use of any deformed, rough-surfaced bar having a cross-section area equal to or greater than that shown on the plans will be permitted. These bars shall be held in place while the concrete is being poured, by pins left in place.

Longitudinal Bars in Edges of Pavement.—When required, bars having the cross section and length as shown on the plans shall be placed in the edges of the concrete pavement, parallel to the center line, in the manner indicated. Each bar shall be painted at the site of the work with one coat of red lead or sublimed blue lead paint conforming to the requirement of Secs. 33-3 and 33-6 "Paint for Steel Bridges." When the paint coat has entirely dried, and immediately before placing of the bar in the concrete, the bar shall also be coated with a thin film of heavy oil. The bars shall be held in position by steel pins driven and left in place, spaced as shown on the plans. The pins shall be of a type approved by the engineer and shall be of such a character that the vertical support to the rods will be supplied at the ground line and the lateral support by contact with the side forms. Where longitudinal bars are lapped, the free ends at the laps must be adequately supported. Care shall be taken that the elevation of the bars is maintained throughout the placing and tamping of the concrete.

Steel.—All steel bars used in the concrete pavement shall meet with the requirements of Specification XXVII, "Reinforcement."

Mixing Conditions.—No concrete shall be mixed while the temperature is at or below 35°F., and no materials containing frost shall be used. Bags of cement or fine aggregate which contain lumps or crusts of hardened material shall not be used. The concrete shall be mixed only in

such quantity as is required for immediate use and any which has developed initial set, or has been mixed longer than 30 min. shall not be used.

All concrete shall be effectively protected from the action of frost for a period of at least 5 days after it is deposited in the work. All concrete which has not been properly protected as above specified and concrete which may have become damaged by frost shall be replaced at the contractor's expense upon written notice from the engineer. Concrete shall not be placed upon a frozen subgrade.

Placing and Finishing Concrete.—The concrete shall be placed between the side forms in successive batches for the entire width to at least the full thickness of the pavement and thoroughly spaded along the forms.

After it has been deposited, it shall be struck off in such manner that the crown elevation shall be ¼ in. higher than the finished pavement and then compacted or finished mechanically with a power driven machine approved by the engineer until all voids are removed and the concrete thoroughly compacted. The mechanical compacting machine or finishing machine shall go over each area of the pavement at least three times, at such intervals as will give the desired results. The mechanical compacting machine or finishing machine shall be kept in good repair at all times and shall operate so as to give the desired finish over the entire surface of the pavement.

Immediately after the final compacting, the surface shall be belted once, operating the belt with a combined cross wise and longitudinal motion. If the belt attached to the finishing machine does not, in the opinion of the engineer, produce the desired results, independent belts shall be supplied and used. Care shall be taken not to work the crown out of the pavement, nor to permit the edges of the belt to dig into the surface of the concrete.

The belt used shall be of canvas rubber composition or canvas from two to four ply and shall have a width of not less than 6 in. and a length of at least 2 ft. longer than the width of the pavement. The belt shall be cleaned after each day's run and shall be oiled as required by the engineer.

Immediately after the surface of the pavement has been given the preliminary belting, it shall be tested at all points by means of a 10-ft. straightedge and all variations greater than ¼ in. shall be eliminated by means of a long-handled wooden float or straightedge.

Immediately after the compacting and finishing operations have been completed, all surplus water, laitance, or inert material shall be worked off by one of the following methods:

(*a*) The entire surface of the pavement shall be scraped with a straightedge having a length of not less than 8 ft. nor more than 15 ft.

If not more than 10 ft. in length, the straightedge may be operated by a long handle from the side of the pavement.

If more than 10 ft. in length, it shall be operated from bridges resting on the side forms.

The scraping or floating shall be accomplished by drawing the straightedge from the crown of the pavement to each side in such manner that all laitance, surplus water, and inert materials shall be removed from the surface. At each operation of the straightedge, there shall be a one-half lap longitudinally.

(*b*) The surface of the pavement shall be rolled with a smooth roller, not less than 6 ft. in length, operated by means of ropes or long handles.

The roller shall be operated slowly in a transverse direction from one edge of the pavement to the other and back again over the same area. A one-half lap shall then be made, taking great care not to mar or displace the concrete, and the rolling continued in the same manner until the entire surface has been rolled.

(*c*) Any other method approved by the engineer.

The surface shall again be checked with a 10-ft. straightedge, and any irregularities over ¼ in. shall be eliminated.

When the surface of the concrete is free from water and just before the concrete obtains its initial set, it shall be given a final belting to produce a uniform finish. The final belting shall be of short, rapid, transverse strokes, having a sweeping longitudinal motion. Badly worn belts shall be discarded and new ones used.

The edges of the pavement shall be carefully finished with an edger having a radius of about ¾ in. at about the time the concrete takes its initial set. This shall be done in such manner that the edge will be left smooth and true to line.

As soon as the pavement has set sufficiently to permit walking on it and not later than 10 o'clock of the morning following the placing of the concrete, it will be again thoroughly straightedged by the engineer and all variations exceeding ¼ in. shall be plainly marked. The contractor shall at once eliminate such variations by the use of a carborundum brick and water. The rubbing shall not be continued after contact with the coarse aggregate is made, and, in no case, shall it be done in such manner or carried to such extremes that the bond of the concrete will be broken.

For each variation greater than ¼ in. remaining after the above provisions have been complied with, there shall be deducted from the amount due or which may become due the contractor, the cost of 1 sq. yd. of pavement at the contract unit price per square yard, exclusive of the cost of cement.

The use of a bush hammer or similar device to remove irregularities after the concrete has taken its final set will not be permitted.

The finished concrete pavement shall be uniform in character and appearance, free from voids and depressions, and true to the cross-sections shown on the plans.

Hand Finishing.—Compacting and finishing by hand will not be permitted except in the case of a break-down of the mechanical compacting machine or other emergency, and then only upon special permission from the engineer. If compacting and finishing by hand are necessary, at least one man for each 150 lin. ft. of pavement laid per day, and at no time less than two men, shall be engaged at the exclusive work of compacting the concrete.

Immediately after the final compacting, the pavement shall be rolled, the roller being operated as specified hereinbefore, and immediately thereafter the surface belted and finished as herein specified.

Auxiliary Finishing Equipment.—The following auxiliary finishing equipment shall be provided for emergency use and shall be available at all times:

(*a*) A bridge, designed so that when placed on the forms no part shall come in contact with the pavement. It shall be such that it can be readily transported from place to place. The use of an auxiliary belting machine as a substitute for the bridge will be permitted.

(*b*) A tamping templet, approved by the engineer, the tamping face of which shall be approximately 4 in. The templet shall have sufficient rigidity to maintain the true cross section of the pavement.

(*c*) An extra finishing belt of the type described above.[1]

(*d*) Two or more 10-ft. straightedge timbers made from suitable material.

(*e*) Long-handled wood floats having a blade at least 3 ft. in length and 6 in. in width.

Joints.—At the close of each day's work, or when the process of depositing concrete is stopped for a length of time such that, in the opinion of the engineer, the concrete will take its initial set before work is resumed, a butt construction joint shall be made perpendicular to the center line of the pavement. Sections less than 10 ft. in length between header boards will not be permitted.

A clean plank having a thickness of not less than 3 in., a width of not less than the thickness of the pavement, and a length not less than the width of the pavement shall be used for this joint. It shall be cut true to the crown of the finished pavement and shall be accurately set and held to place in a plane at right angles to the longitudinal surface of the pavement. The metal center joint must be placed in contact with the header board. Where longitudinal bars are used, they shall project at least 24 in. beyond the construction joint. Vertical open slots in the header board will be permitted to facilitate the removal of the header board and the placing of the bars.

Any surplus concrete remaining on the subgrade, upon resumption of work, shall be removed. The header board shall then be carefully

[1] See page 208.

removed and fresh concrete deposited against the old in such manner as to avoid any rise or depression in the joint which will vary more than ¼ in. from a 10-ft. straightedge.

Construction of Pavement in Two Strips.—The contractor will be permitted to construct the pavement in two strips of equal width, provided he complies strictly with the plans and specifications in all other respects.

Protection and Curing.—After the concrete pavement has been finished as specified herein, it shall be protected against rapid drying by covering with 10 or 12 oz. burlap, wetted thoroughly and laid directly upon the surface as soon as, in the judgment of the engineer, the concrete has sufficiently set to prevent marring the surface. The burlap shall be kept continuously wet by sprinkling during the day as required. Unless the foregoing provisions have been complied with, work shall be immediately suspended.

As soon as practicable after the concrete has taken its final set and not later than 10 o'clock a. m. on the day following the placing of the concrete, all burlap shall be removed and the pavement cured by one of the methods described below.

(*a*) *Earth Covering.*—The edges of the pavement shall be banked and the entire surface covered with at least 2 in. of earth, the thickness of the covering to be determined after the earth has been thoroughly saturated with water. The earth covering shall be thoroughly saturated with water each day for a period of 8 days and it shall remain on the surface for at least 14 days from the time of its application and for a longer period of time if weather conditions, in the opinion of the engineer, make it desirable. It shall then be scraped off and spread over the earth shoulders on either side of the pavement in a thin, uniform layer.

(*b*) *Straw Covering.*—The entire surface shall be covered immediately with straw. The straw covering shall be at least 4 in. thick after having been saturated with water and shall be kept wet in the same manner and for the same length of time as specified for earth covering. It shall then be removed and disposed of, so as to leave the road in a sightly condition, but under no circumstances shall it be burned on the pavement surface or in close proximity with the edges.

(*c*) *Ponding Method.*—The method of curing known as ponding may be used if desired. If this method is used, the surface shall be flooded with water held by means of earth dikes, and shall be kept covered with water for a period of at least 8 days.

(*d*) *Calcium Chloride.*—The surface shall be uniformly covered with flaked or granulated calcium chloride, applied at the rate of not less than 2½ lb. per square yard of pavement, spread by a squeegee or suitable mechanical device so that a uniform distribution

is obtained. Spreading by means of shovels and brooms will not be permitted. All lumps shall be broken and uniformly distributed over the pavement or entirely removed.

It shall not be applied until a period of at least 10 hours has elapsed after the pavement is laid. It shall not be applied during a rain. If a rain falls within a period of 2 hours following the application of the chloride, an additional application must be made.

Curing When Temperature is Below 50°F.—When the average daily temperature is below 50°F., curing by the above methods shall be omitted, if so ordered by the engineer. In this event, the edges of the pavement shall be thoroughly banked with earth and the entire surface covered either with two or more inches of each or with straw for a period of 2 weeks.

Opening to Traffic.—The pavement shall be kept closed to traffic, for a period of at least 21 days. If, in the opinion of the engineer, weather conditions make it advisable, the pavement shall be kept closed to traffic for a longer period of time than the 21 days mentioned.

Within 21 days after placing the pavement and before it is opened to traffic, an earth berm shall be constructed along each edge. This berm shall be built to the full height of the pavement, shall be of suitable width and sufficiently compacted to prevent underwash of the pavement. It shall be maintained until the earth shoulders are finally completed.

Pavement Adjacent to Railroad Crossings and Bridges.—Pavement adjacent to railroad crossings and bridges, and over bridges, shall be constructed in accordance with the special designs shown on the plans. The cost of constructing such pavement, including all labor and materials, shall be included in the contract unit price per square yard for portland cement concrete pavement.

Unless otherwise specified on the plans, the spaces between the edges of the pavement and bridge rails shall be filled with broken stone or gravel, and such material shall be included in the contract unit price per square yard for portland cement concrete pavement. Bituminous material for joints adjacent to railroad crossings or bridges shall also be included in said unit price.

Basis of Payment.—This work shall be paid for at the contract unit price per square yard for "portland cement concrete pavement," which price shall include all reinforcing steel, metal center joint, painting of steel, all other materials required herein, equipment, tools, labor, and all work incidental to the construction thereof.

CHAPTER 14

SAMPLING

Sampling is the process of selecting small, representative quantities of a given material for purposes of examination or testing. Since the quality of a large amount of material is to be determined on the basis of the sample selected, it is exceedingly important that the portion taken be representative. Much is often left to the judgment of the person doing the sampling as to whether the material is accepted or rejected.

Cement, aggregates, and water are the only concrete materials to be sampled, with the possible exception of curing agents and

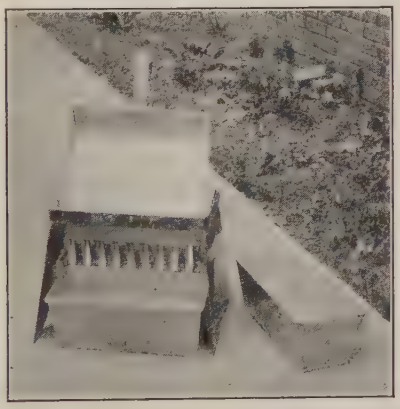


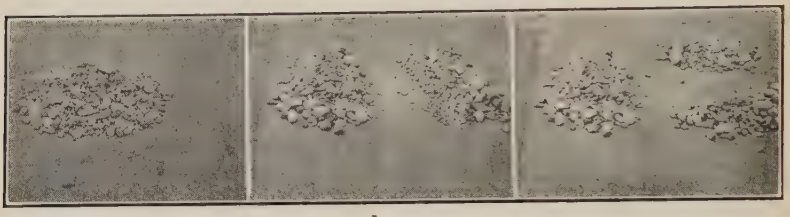
FIG. 102.—Sample splitter for securing representative test samples of sand.

admixtures. Methods for sampling and testing of cement and aggregates are prescribed by the American Society for Testing Materials and are usually followed by engineers.

Cement.—Cement is normally sampled by the purchaser after it is in the car ready for shipment. The manufacturer normally takes his samples from the bins. A sample is taken for each 50 bbl. when loaded in the cars or one for each 200 bbl. when taken from the bins. If it is not desired to test a sample for each 50 bbl., a composite sample may be taken for

each car. The composite sample is gotten by taking small quantities from one out of every 40 sacks and then mixing them together before testing.

Samples taken upon arrival at the job should be placed in clean moist-proof containers for transfer to the laboratory. If the container has been used for any other purpose previously, it should be cleaned out thoroughly and be dry. Sugar bags should not be used because a few grains of sugar are likely to reduce considerably the strength of concrete or mortar in which the cement may be used.



a *b* *c*

FIG. 103.—Selecting test sample of pebbles by quartering method. *a*, full sample *b*, cut in two *c*, one of the halves cut in two.

Aggregates.—Before using aggregates from any pit or quarry for concrete, the general quality of the material in the deposit should be determined. Knowledge should be had of the durability, strength, wearing qualities, and soundness. The deposit in a pit or quarry may vary considerably from place to place so that a large number of samples should be secured before removal operations are begun, or the deposit should be watched and checked occasionally as work progresses. Knowledge of material contained in neighboring pits or quarries is helpful in judging the quality of the material in question.

After the materials in any pit or quarry have been accepted for quality, certain other tests must be made on each carload. Gradation and cleanness are the items needing constant control. Sand, because of its size and moisture content, is rather uniform as loaded into a car. Coarse aggregate has a tendency to segregate according to size of particles. The coarser ones roll down to the edge of the pile and the finer ones concentrate in the center under the unloading spout.

Preparing Samples for Testing.—The samples as selected must be further reduced in size before the individual tests can be

made. Again, special efforts are made to select representative portions for testing. Cement should be thoroughly mixed and passed through a 20-mesh sieve. Aggregates should be well mixed which may be done with a shovel or trowel. The portion for testing is selected by the quartering method. The original sample is spread in an even layer and then divided into two parts. One of these parts is divided in two and the process continued until a part is secured which has the required amount in it for the test. In case sample splitters are not available, the division may be made with a shovel or a trowel.

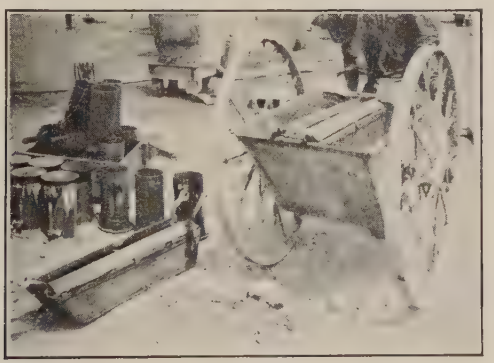


FIG. 104.—Sampling concrete. Sampler box was placed in the center of the concrete cart to receive a representative portion of the concrete going into the cart.

Specifications for Sampling.—The A. S. T. M. specifications for sampling cement and aggregates are quoted in full.

SAMPLING OF PORTLAND CEMENT[1]

16. *Number of Samples.*—Tests may be made on individual or composite samples as may be ordered. Each test sample should weigh at least 4 lb.

17*a*. *Individual Sample.*—If sampled in cars, one test sample shall be taken from each 50 bbl. or fraction thereof. If sampled in bins, one sample shall represent each 200 bbl. unless otherwise specified by the purchaser.

b. *Composite Sample.*—If sampled in cars, one sample shall be taken from one sack in each 40 sacks (or 1 bbl. in each 10 bbl.) and combined to form one test sample. If sampled in bins or warehouses, one test

[1] Quoted from "Standard Specifications and Tests for Portland Cement," of the A. S. T. M., serial designation C9-26. The paragraph numbers are those given in the A. S. T. M. standard.

sample shall represent not more than 200 bbl. unless otherwise specified by the purchaser.

18. *Method of Sampling.*—Cement may be sampled at the mill by any of the following methods that may be practicable, as specified:

a. From Conveyor Delivering to the Bin.—At least 4 lb. of cement shall be taken from approximately each 100 bbl. passing over the conveyor. This may be secured by taking the entire test sample at a single operation, known as the "grab method," or by combining several portions taken at regular intervals, known as the "composite method."

b. From Filled Bins by Means of Proper Sampling Tubes.—Tubes inserted vertically may be used for sampling cement to a maximum depth of 10 ft. Tubes inserted horizontally may be used when the construction of the bins permits. Samples shall be taken from points well distributed over the face of the bin.

c. From Filled Bins at Point of Discharge.—Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement contained in the bin, as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before drawing of the cement is started.

19. *Person Taking Sample.*—The sampling shall be done by or under the direction of a responsible representative of the purchaser.

20. *Treatment of Sample.*—Samples preferably shall be shipped and stored in moisture-proof, air-tight containers. Samples shall be passed through a sieve having 20 meshes per linear inch in order thoroughly to mix the sample, break up lumps, and remove foreign materials.

STANDARD METHODS OF SAMPLING STONE, SLAG, GRAVEL, SAND, AND STONE BLOCK FOR USE AS HIGHWAY MATERIALS

INCLUDING SOME MATERIAL SURVEY METHODS

A. S. T. M. Serial Designation D75-22

1. Samples of all materials for test upon which is to be based the acceptance or rejection of the supply shall be taken by the engineer or his authorized representative. Samples for inspection or preliminary test may be submitted by a producer or owner of the supply.

I. Sampling of Stone

A. Sampling of Stone, from Ledges or Quarries for Quality

2. *Inspection.*—The ledge or quarry face shall be inspected closely to determine any variation in different layers. Any difference in color or structure shall be observed, and, if necessary to secure unweathered specimens, pieces broken from different layers.

3. *Sampling and Size.—a.* For standard stone test, separate samples shall be taken of at least 30 lb. each of fresh unweathered specimens from all layers that appear to vary in color or structure. When more than one piece is taken, the minimum size shall be 2 in., except that there shall be one piece of each sample of a minimum size of $4 \times 5 \times 3$ in. on which the bedding plane is marked and which shall be free from seams or fractures to be used in the toughness or compression test.

b. The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

4. *Record.*—In addition to the general information accompanying all samples, samples from local ledges not commercial sources shall contain the following: name of owner, approximate quantity available (if the quantity is very large, this can be recorded as practically unlimited), amount and character of overburden or stripping, haul to nearest point on road where the material is to be used, character of haul (kind of road and grade), also some detailed record of the extent and location of the material represented by each sample. For this purpose a sketch, plan, and elevation showing the thickness and location of the different layers is recommended.

B. Sampling of Stone from Commercial Quarries

5. *For Quality.*—Where practical, samples from commercial quarries shall be taken from the ledge or quarry face and the same procedure shall be followed as when sampling local ledges.

6. *For Size.*—At the plant, the following factors affect the size of broken stone: size and shape of screen openings, length of screen sections, the angle of screen with horizontal, the speed of screen rotation, and the rate at which the screen is fed. A general inspection and record of these conditions shall be made. The sample shall be taken preferably from cars or boats while loading from stock piles or bins. It is recommended, in order that the sample may be representative, that separate samples be taken at different times while the material is being loaded. If the sample has to be taken from the bin or stock pile, several samples shall be taken from different parts of the stock pile and from the top of the bin and the loading chute. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

7. *Sampling at Delivery.—a.* Where it is not practical to visit the plant, samples for both quality and size shall be taken from different parts of the car or boat during unloading. It is recommended that separate samples be taken from the top, middle, and bottom of car or boat. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method. The results of tests on crushed stone for quality are not considered comparable with

results from samples specially broken for test in the laboratory, but the general quality of the stone can be ascertained and check tests on various shipments should indicate any change in quality. In this case, tests for both quality and size can be made on the same sample.

b. Where test is to be made for size only, it is recommended that a small set of screens and a pair of scales or some unit measure receptacle for measuring volume be used for field testing in order not to delay decision on the use of the material. Occasional check tests can be obtained from the laboratory to assure a fair degree of accuracy in field testing.

8. *Size of Samples.*—*a.* The sample of crushed stone for mechanical analysis shall weigh at least fifty times the weight of the largest piece therein.

b. The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

C. Sampling of Field Stone and Boulders

9. *For Quality.*—A detailed inspection of the deposits of field stone and boulders, over the area where the supply is to be obtained, shall be made. The different kinds of stone and its state of preservation in the various deposits shall be recorded.

10. *Separate Samples.*—Separate samples shall be taken of all stone of different classes that a visual inspection indicates, from state of preservation and degree of lamination, would be considered for use in construction.

11. *Record.*—Records accompanying, samples of field stone and boulders, in addition to general information, shall contain the following:

a. Location of Supply.—The plotting of the field stone and boulder area on a U. S. topographic or a similar map is recommended for this purpose.

b. Approximate Quantity Available.—A fairly accurate estimate of amount of stone in fences can be made by measuring a cross-section and pacing the length. It is more difficult to estimate the amount of stone scattered on the ground, and ordinarily such deposits do not pay to work unless quite congested.

c. Information regarding the percentage of different classes of stone which were sampled and the percentages of material which can be rejected by visual examination and may have to be handled and spoiled. This information regarding the percentages of different kinds of material can only be estimated and the degree of accuracy attained will depend almost entirely upon the experience and skill of the individual.

II. Sampling of Blast-furnace Slag

12. *For Size and Quality.*—It is recommended that blast-furnace slag be sampled for size and quality by the method specified for broken stone.

III. Sampling of Sand and Gravel

A. Non-commercial Deposits

13. *Definition.*—Non-commercial, as used here, includes all undeveloped sand and gravel deposits and all developed deposits where the material is not washed or screened.

14. *Sampling.*—*a.* The investigator should realize that few if any natural sand and gravel deposits are uniform, and when a sample is taken, the quantity of material in the deposit similar to the sample shall be ascertained as nearly as possible.

b. Where possible, samples of sand shall be taken when it is in a damp condition.

c. If the deposit is worked as a bank or pit and has an open face, the sample shall be taken by channeling the open face so as to represent material that visual inspection indicates could be used. Care shall be taken to eliminate any overburden or stripping at the top or any that has fallen along the face from the top. It is necessary, especially in small deposits, to excavate test pits some distance back of and parallel to the face to determine the extent of the supply. The number and depth of these pits depend on the quantity of material that is to be taken from the deposit. Separate samples shall be taken from the face of the bank and from test pits. These shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

d. Deposits that have no open face shall be sampled by means of test pits. The number and depth of these will depend on local conditions and the amount of material to be used from the source. A separate sample shall be taken from each pit, and where visual examination indicates no radical difference in size of grain, color, etc., these shall be well mixed in a composite sample and the sample for test obtained by the quartering method. Where visual inspection indicates a distinct difference in material from different pits, separate samples shall be taken for the test.

e. It is suggested that the colorimetric test be used for determining the percentage of organic material.

15. *Record.*—In addition to the general information accompanying all samples from sand and gravel deposits not commercial sources, the same detailed information shall be supplied as with samples of stone taken from local ledges.

B. Commercial Sand and Gravel Plants

16. *Sampling for Quality.*—Samples of both sand and gravel from commercial screening or washing plants shall be taken from the bins or storage piles preferably while the material is being loaded from these

supplies. The sand and gravel shall be sampled as separate units and shipped as such. It is difficult to secure a representative sample from stock piles and bins, and if conditions require sampling from these sources, the following is recommended: Separate samples shall be taken from different parts of the stock pile, care being taken to avoid sampling a segregated area of coarse-grained material which is likely to exist at the base of the pile. In sampling from a bin, separate samples shall be taken from the top and the loading chute. At the latter place at least ½ cu. yd. of material shall be run off and representative samples taken from it. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

17. *Sampling for Size.*—The size of sand and gravel will be affected by the same factors as broken stone, and the same inspection is necessary. In addition, the relative amount of water used in screening must be taken into consideration. The same procedure for taking a sample of broken stone for size is recommended for sampling sand and gravel for size, both at plant and at delivery.

18. *Sampling at Delivery.*—Where it is not practical to visit the plant, samples for both quality and size shall be taken from different parts of the car or boat during unloading. It is recommemded that separate samples be taken from the top, middle, and bottom of the car or boat. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

C. Quantity of Sand and Gravel Samples

19. *Run of Bank.*—Samples of run of bank (where the sand and gravel are combined) shall consist of at least 100 lb. of material where the gravel content is 50 per cent or more of the whole. If the gravel is less in percentage, the sample shall be increased in proportion. For example, where the gravel percentage is 25 per cent of the whole, the sample should contain 200 lb.

20. *Sand.*—Samples of sand shall contain at least 20 lb. of material.

21. *Gravel.*—Samples of gravel shall contain at least 50 lb. of material.

22. *Sample for Concrete Test.*—The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

IV. Sampling of Miscellaneous Materials

23. Samples of slag sand, screenings, mine tailings, and all other materials used as a substitute for sand and gravel or broken stone shall be inspected in the same manner and samples taken in the same way as the materials for which they are substituted.

V. Sampling of Stone Block

24. *Where Sampled.*—Samples shall be taken either at the quarry or from cars or boats as directed by the engineer. They shall be representative of the block which it is proposed to use, and no sample shall include blocks that would be rejected by visual inspection.

25. *Size of Sample.*—The sample shall consist of at least six blocks and the bedding plane shall be marked on at least two of these.

VI. General Directions for Shipping and Marking Samples

26. *Stone and Slag.*—Samples of ledge stone, crushed stone, and slag shall be shipped in a secure box or bag.

27. *Stone Block.*—Samples of stone block shall be securely crated.

28. *Gravel, Sand, Etc.*—Samples of run-of-bank gravel, sand screenings, and other fine material shall be shipped in a tight box or closely woven bag so there shall be no loss of the finer particles.

29. *Marking.*—Each sample or separate container shall be accompanied by a card or regular form, preferably in the container, giving the following information: by whom taken; official title or rank of the sampler; by whom submitted; source of supply; proposed use for the material; in case of commercial supplies, daily production; geographic location, shipping facilities (name of railroad, canal, or river, or other common carrier); and price of material.

CHAPTER 15

TESTING

Testing is the process of determining certain facts or qualities about a material. Every material which is used in construction must have given qualities in order to do its part in the structure. Laboratory and field tests have been devised to determine these qualities in a comparatively short interval of time. In writing specifications for materials certain maximum or minimum limits must be set and these limits must have some relation to the actual needs for the material as used.

The results of tests can frequently be varied by varying the method of doing the work. In order to prevent such deviations, specifications must be prescribed for the method to be followed in making each test. The American Society for Testing Materials has prepared methods of testing for practically all the tests commonly used on concrete materials. These specifications are a great convenience to the engineer and because of their wide use make it possible for the manufacturers to supply a larger number of users. Even with the methods carefully specified, there are often wide variations in test results, many of which are caused by failure of the tester to observe all of the details.

Importance of Temperature Control.—Much of the variation in strength test results is caused by changes in the temperature of the specimens during the curing period. Little appreciation has been had of the effect of small changes in temperature on the compressive strength of concrete or mortars. The A. S. T. M. specifications covering the curing of laboratory test specimens permit a variation in the temperature of the curing room of 15°F. Tests by the author (see p. 173) indicate that for each degree change in temperature, the strength is effected 35 lb. per square inch, when the concrete is kept at 70°F. for the first 24 hours. Approximately 525 lb. per square inch variation is possible within the limits of the specifications. Often no attempt is made to control temperature and it is no wonder that the strength results vary considerably. Strength of briquets may also be effected by changes in temperature.

Tests on Materials.—Instructions for the performance of all the regular tests on portland cement and aggregates are given in detail beginning on page 241.

Tests on Concrete.—Strength is the chief requirement for concrete and is also a good indication of its other qualities so that the only tests developed and used extensively are strength tests. There are two types of strength test known as the compression test and the beam test. In the former test, specimens in the form of cylinders are loaded in direct compression until failure occurs. In the beam test the concrete is molded into a beam and tested as such. Results are given in terms of the modulus of rupture.

Fig. 105.—Test cylinders, before and after breaking.

Each of the above tests has certain advantages and disadvantages. The beam test is still comparatively new and is in the process of development. The compression test results are easily understood by the average person whether he be an engineer or not. The values are equal to the total load divided by the area of the specimen. The apparatus required however, is expensive and can not be used in the field. The test specimens are small and can be handled conveniently by one person. The beam test results are not readily understood by the average person, which is a decided disadvantage. The apparatus, however, is comparatively light and inexpensive. It can be taken to various jobs and the tests made in the presence of interested parties. The specimens are large and can not always be handled by one person. The beam test has been developed by the state highway departments and is particularly applicable to pavement concrete.

Compression Tests

The American Society for Testing Materials has prepared methods for making concrete specimens, both in the field and in the laboratory. These methods are quoted in full and are much in detail, so that it seems unnecessary to give a discussion in addition.

Standard Method of Making and Storing Specimens of Concrete in the Field

A. S. T. M. Serial Designation C31-27

1. *Scope.*—This method is intended to apply to the molding and storing of test specimens of concrete sampled from concrete being used in construction.

2. *Size and Shape of Specimens.*—The test specimens shall be cylindrical in form with the length twice the diameter. The standard shall

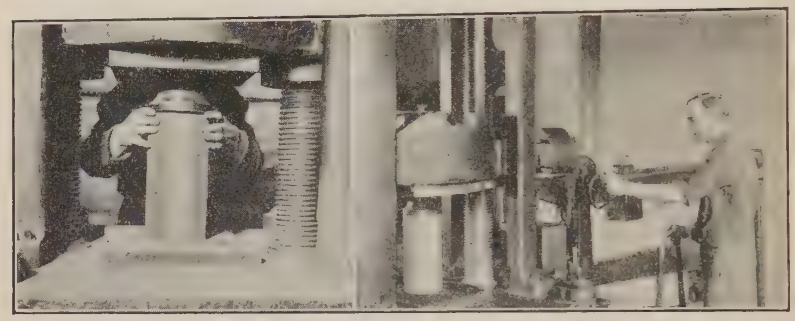


Fig. 106.—Testing concrete cylinders. *Left*, centering under spherical bearing block. *Right*, applying load, the amount being registered on the weighing device at the right.

be 6- by 12-in. cylinders where the coarse aggregate does not exceed 2 in. in size; for aggregates larger than 2 in., 8- by 16-in. cylinders shall be used; 2- by 4-in. cylinders may be used for mixtures without coarse aggregate.

3. *Molds.*—(*a*) The molds shall be cylindrical in form, made of non-absorbent material, and shall be substantial enough to hold their form during the molding of the test specimens. They shall not vary in diameter more than $\frac{1}{16}$ in. in any direction, nor shall they vary in height more than $\frac{1}{16}$ in. from the height required. They shall be substantially water tight so that there will be no leakage of water from the test specimen during molding.

Note.—The best type of mold consists of lengths of cold-drawn steel tubing, split along one element and closed by means of a circumferential band and bolt. Satisfactory molds can be made from lengths of steel water pipe machined on the inside, from rolled metal plates, from galvanized steel, machined iron or steel castings. Paraffined cardboard molds will give good results under expert supervision.

(*b*) Each mold shall be provided with a base plate having a plane surface and made of non-absorbent material. This plate shall be large enough in diameter to properly support the mold without leak-

age. Plate glass or planed metal are satisfactory for this purpose. A similar plate should be provided for covering the top surface of the test specimen when molded.

(*c*) Suggestions for suitable molds are shown in Figs. 107, 108 and 109.

4. *Sampling of Concrete.*—(*a*) Concrete for the test specimens shall be taken immediately after it has been placed in the work. All the concrete for each sample shall be taken from one place. A sufficient number of samples—each large enough to make one test specimen—shall be taken at different points so that the test specimens made from them will give a fair average of the concrete placed in that portion of the structure selected for tests. The location from which each sample is taken shall be noted clearly for future reference.

(*b*) In securing samples, the concrete shall be taken from the mass by a shovel or similar implement and placed in a large pail or other receptacle, for transporting to the place of molding. Care shall be taken to see that each test specimen represents the total mixture of the concrete from a given place. Different samples shall not be mixed together but each sample shall make one specimen.

5. *Molding Test Specimens.*—(*a*) The pails or other receptacles containing the samples of concrete shall be taken as quickly as possible to the place selected for molding test specimens. To offset segregation of the concrete occurring during transportation, each sample shall be dumped into a non-absorbent water-tight receptacle and, after slight mixing, immediately placed in the mold.

(*b*) The test specimens shall be molded by placing the concrete in the mold in layers 3 to 4 in. in thickness. Each layer shall be puddled with 25 strokes with a $\frac{5}{8}$-in. rod 24 in. in length bullet pointed at the lower end. After puddling the top layer, the surface concrete shall be struck off with a trowel and covered with the top cover plate which may later be used in capping the test specimen.

6. *Capping Specimens.*—Two to four hours after molding, the test specimens shall be capped with a thin layer of stiff neat-cement paste in order that the cylinder may present a smooth end for testing. The cap shall be formed by means of a piece of plate glass $\frac{1}{4}$ in. in thickness or a machined metal plate $\frac{1}{2}$ in. in thickness and of a diameter 2 or 3 in. larger than that of the mold. The plate shall be worked on the fresh cement paste until it rests on top of the mold. The cement for capping should be mixed to a stiff paste 2 to 4 hours before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by oiling the plates or by inserting a sheet of paraffined paper.

7. *Removal of Specimens from Molds.*—At the end of 48 hours the test specimens shall be removed from the molds and buried in damp sand except in case the molds shown in Fig. 109 are used, when they may

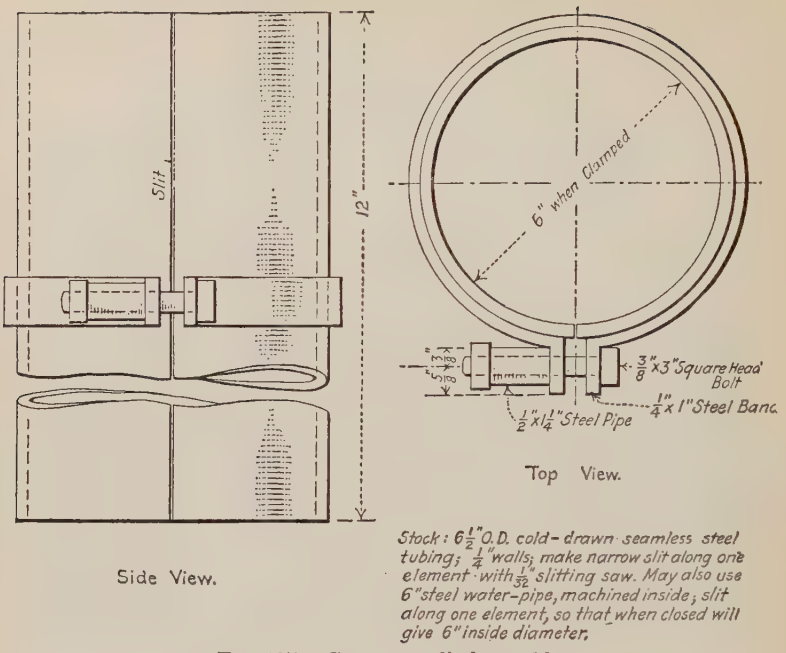


Fig. 107.—Concrete cylinder mold.

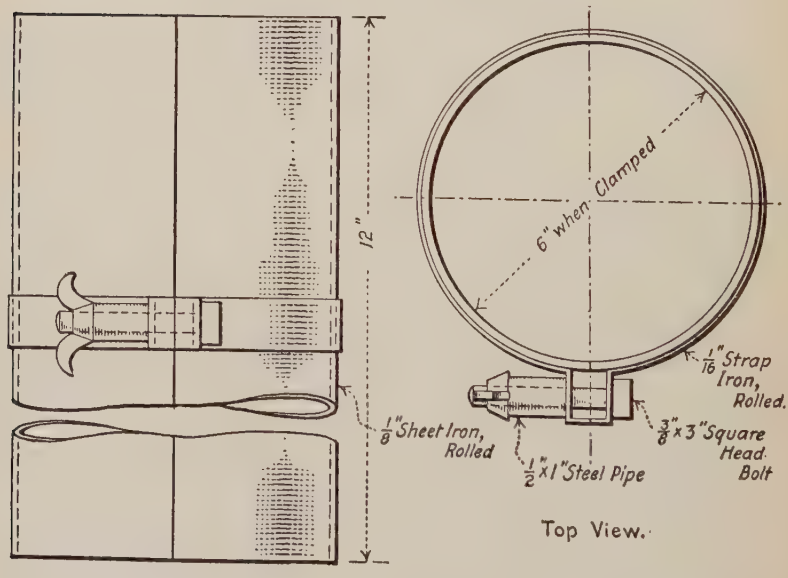


Fig. 108.—Concrete cylinder mold.

be buried in damp sand without removal of the mold, thus permitting shipping in the molds.

8. *Storage of Specimens.*—(*a*) The test specimens shall remain buried in damp sand until 10 days prior to the date of test. They shall then be well packed in damp sand or wet shavings and shipped to the testing laboratory, where they shall be stored either in a moist room or in damp sand until the date of test.

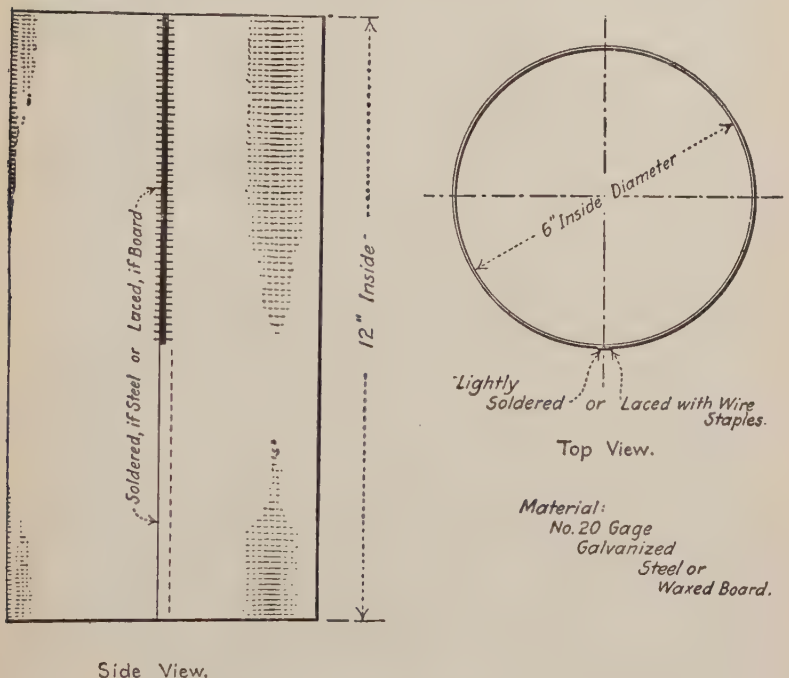


FIG. 109.—Concrete cylinder mold.

(*b*) Should a 7-day test be required, the test specimens shall remain at the work as long as possible to harden and then shall be shipped so as to arrive at the laboratory in time for test on the required date.

(*c*) Test specimens shall be protected from drying after removal from damp storage and before testing.

STANDARD METHODS OF MAKING COMPRESSION TESTS OF CONCRETE

A. S. T. M. Serial Designation C39-27

1. *Scope.*—These methods are intended to cover compression tests of concrete made in a laboratory where accurate control of quantities

of materials and test conditions is possible. They are designed to apply primarily to hand-mixed concrete compression specimens, but may be used with slight modification in making tests of concrete for wearing resistance, bond between concrete and steel, impermeability, etc. The investigation of machine-mixed concrete will require certain obvious changes in the methods. For methods of conducting compression tests of concrete specimens made during the progress of construction work, see the Standard Method of Making and Storing Specimens of Concrete in the Field (Serial Designation C31) of the American Society for Testing Materials.[1]

2. *Preparation of Materials.*—Materials shall be brought to room temperature (18 to 24°C., 65 to 75°F.) before beginning the tests. Cement shall be stored in a dry place; preferably in covered metal cans. The cement shall be thoroughly mixed in advance, in order that the sample may be uniform throughout the tests. It shall be sieved through a No. 16 (1,190-micron) sieve and all lumps rejected. Aggregates shall be in a room-dry condition when used in concrete tests. In general, aggregates should be separated on the No. 4 (4,760-micron), ⅜-in. and 1½ in. sieves and recombined to the average original sieve analysis for each batch. Fine aggregate should be separated into different sizes also, in cases where unusual gradings are being studied.

3. *Sampling for Preliminary Tests.*—Representative samples of all concrete materials shall be secured for preliminary tests prior to the proportioning and mixing of the concrete. Cement test samples may be made up of a small quantity from each sack used in the concrete tests. Test samples of aggregates may be taken from larger lots by quartering.

4. *Cement Tests.*—Cement shall be tested in accordance with the methods described in the Standard Specifications and Tests for Portland Cement (Serial Designation C9) of the American Society for Testing Materials.[1]

5. *Fine Aggregate Tests.*—Fine aggregates (passing through a No. 4 (4,760-micron) sieve) shall be subjected, when required, to the following tests of the American Society for Testing Materials:

(*a*) Sieve analysis test made in accordance with the Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation C41).[1]

(*b*) Test for organic impurities made in accordance with the Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation C40).[1]

(*c*) Test for quantity of silt, clay and dust made in accordance with the Tentative Method of Decantation Test for Sand and Other Fine Aggregates (Serial Designation D136-22T).[2]

[1] 1927 Book of A. S. T. M. Standards, Part II.

[2] 1927 Book of A. S. T. M. Tentative Standards.

(*d*) Test for unit weight made in accordance with the Standard Method of Test for Unit Weight of Aggregate for Concrete (Serial Designation C29).[1]

(*e*) Strength test of 1:3 mortar by weight at 7 and 28 days in comparison with standard sand mortar in accordance with Standard Specifications and Tests for Portland Cement (Serial Designation C9).[1]

6. *Coarse Aggregate Tests.*—Coarse aggregates (retained on a No. 4 (4,760-micron) sieve) shall be subjected when required to the following tests:

(*a*) Sieve analysis test as specified in Sec. 5 (*a*);

(*b*) Test for quantity of silt, clay and dust made in accordance with Standard Method of Test for Quantity of Clay and Silt in Gravel for Highway Construction (Serial Designation D72) of the American Society for Testing Materials.[1]

(*c*) Test for unit weight as specified in Sec. 5 (*d*).

7. *Mixed Aggregate Tests.*—The unit weight of mixed fine and coarse aggregates as used in concrete tests shall be determined in accordance with the method specified in Sec. 5 (*d*).

8. *Proportioning.*—The quantities of each size of aggregate to be used in each batch shall be determined on the basis of the sieve analysis and the unit weight of the mixed aggregate. The exact quantities of cement and of each size of aggregate for each batch shall be determined by weight. The quantity of water for each batch shall be accurately measured. The quantities of materials may be expressed as (*a*) 1 volume of cement to ---- volumes of total aggregate mixed as used, or (*b*) 1 volume of cement, ---- volumes of fine aggregate, and ---- volumes of coarse aggregate, or (*c*) 1 part by weight of cement ---- parts by weight of fine aggregate, and ---- parts by weight of coarse aggregate.

NOTE.—It is impracticable to give a general method for proportioning concrete for experimental purposes; the details will necessarily vary widely with the purpose for which the tests are made. The following procedure is suggested for specific cases:

(*a*) Vary the cement content by 10 per cent intervals above and below assumed quantity.

(*b*) Vary the proportions of fine to coarse aggregate, measured separately, at intervals of 10 per cent.

(*c*) Vary the quantity of mixing water by intervals of 10 per cent.

9. *Size and Shape of Specimens.*—Compression tests of concrete shall be made on cylinders of diameter equal to one-half the length. The standard shall be 6- by 12-in. cylinders where the coarse aggregate does not exceed 2-in. in size; for aggregates larger than 2 in., 8- by 16-in. cylinders shall be used; 2- by 4-in. cylinders may be used for mixtures without coarse aggregate.

[1] 1927 Book of A. S. T. M. Standards, Part II.

10. *Mixing Concrete.*—(*a*) Concrete shall be mixed by hand in batches of such size as to leave a small quantity of concrete after molding a single test specimen. The batch shall preferably be mixed in a shallow metal pan with a 10-in. bricklayer's trowel which has been blunted by cutting off about 2½ in. of the point, as follows:

(*b*) The cement and fine aggregate shall be mixed dry until the mixture is homogeneous in color;

(*c*) The coarse aggregate shall be added and mixed dry;

(*d*) Sufficient water shall be added to produce concrete of the required workability;

NOTE.—Concrete tests should be made on plastic mixtures. It is of the utmost importance that a uniform degree of workability be secured in tests involving comparisons of different materials and methods.

(*e*) The mass shall be mixed thoroughly until the resulting concrete is homogeneous in appearance.

11. *Workability.*—The workability or plasticity of each batch of concrete shall be measured immediately after mixing by one of the following methods:

(*a*) Slump test made in accordance with the Tentative Method of Test for Consistency of Portland-Cement Concrete (Serial Designation: D138-26T) of the American Society for Testing Materials.

(*b*) Flow test made by placing a metal mold in the shape of a frustum of a cone 6¾ in. in top diameter, 10 in. in bottom diameter, 5 in. in depth, on the table of the flow apparatus.[1] The fresh concrete shall be placed in the mold in two layers. Each layer shall be puddled as described in Sec. 13. Immediately after molding, the surplus concrete shall be struck off with a trowel and the mold shall be removed by a steady upward pull; the table raised ½ in. and dropped 15 times in about 10 seconds by means of a suitable cam and crank. The spread of the fresh concrete due to this treatment expressed as a percentage of the original bottom diameter of the cone is the "flow."

12. *Molds.*—The molds shall preferably be of metal. Each mold shall be provided with a machined metal base plate, and shall be oiled with a heavy mineral oil before using. Particular care shall be taken to obtain tight molds so that the mixing water will not escape during molding.

NOTE.—The best type of mold consists of lengths of cold-drawn steel tubing, split along one element and closed by means of a circumferential band and bolt. Satisfactory molds can be made from lengths of steel water-pipe machined on the inside, from rolled metal plates, from galvanized steel, machined iron or steel castings. Paraffined cardboard molds will give good results under expert supervision.

[1] For a description and illustration of one design for a flow-table, see *Proc.*, Am. Soc. Testing Mats., Vol. XX, Part II, p. 242 (1920), and *Concrete*, June, 1920, p. 274.

13. *Molding Test Specimens.*—Concrete test specimens shall be molded by placing the fresh concrete in the mold in layers 3 to 4 in. in thickness. Each layer shall be puddled with 25 strokes with a $\frac{5}{8}$-in. rod 24 in. in length, bullet pointed at the lower end. After the top layer has been puddled, the surplus concrete shall be struck off with a trowel, and the mold covered with a piece of plate glass at least $\frac{1}{4}$ in. in thickness or a machined metal plate which will be used later in capping the test specimen.

14. *Capping Specimens.*—Two to four hours after molding, the test specimens shall be capped with a thin layer of stiff neat-cement paste in order that the cylinder may present a smooth end for testing. The cap shall be formed by means of a piece of plate glass $\frac{1}{4}$ in. in thickness or a machined metal plate $\frac{1}{2}$ in. in thickness and of a diameter 2 or 3 in. larger than that of the mold. The plate shall be worked on the fresh cement paste until it rests on top of the mold. The cement for capping should be mixed to a stiff paste 2 to 4 hours before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by oiling the plates or by inserting a sheet of paraffined paper.

15. *Curing Test Specimens.*—Concrete test specimens shall be removed from the molds 20 to 48 hours after molding, marked, weighed and stored in damp sand, under damp cloths or in a moist chamber until the date of test. The temperature of the curing room should not fall outside the range of 18 to 24°C. (60 to 75°F.).

16. *Age at Test.*—Tests shall be made at the age of 7 and 28 days; ages of 3 months and 1 year are recommended, if longer-time tests are required.

17. *Sequence of Tests.*—Three to five test specimens should be made on different days in investigations in which accurate comparisons are desired.

18. *Preparation of Tests.*—Compression tests shall be made immediately upon removal of the concrete test specimens from the curing room; that is, the test specimens shall be loaded in a damp condition. The length and average diameter of the test specimen shall be measured in inches and hundredths; two diameters shall be measured at right angles near the mid-length. The test specimen shall be weighed immediately before testing.

19. *Method of Testing.*—In general, only the ultimate compressive strength of the cylinders need be observed. The metal bearing plates of the testing machine shall be placed in contact with the ends of the test specimen; cushioning materials shall not be used. An adjustable bearing block shall be used to transmit the load to the test specimen. The bearing block shall be used on *top* of the specimen in vertical testing machines. The diameter of the bearing block shall be the same or slightly larger than that of the test specimen. The upper or lower

section of the bearing block shall be kept in motion as the head of the testing machine is brought to a bearing on the test specimen.

20. *Application of Load.*—The load shall be applied uniformly and without shock. The moving head of the testing machine should travel at the rate of about 0.05 in. per minute when the machine is running idle.

21. *Record of Tests.*—The total load indicated by the testing machine at failure of the test specimen shall be recorded and the unit compressive strength calculated in pounds per square inch, the area computed from the average diameter of the cylinder being used. The type of failure and appearance of the concrete shall be noted.

22. *Weight of Concrete.*—The weight of the concrete in pounds per cubic foot shall be determined from the weight of the specimens and their dimensions.

23. *Density and Yield.*—Density and yield of concrete when required shall be calculated from the unit volumes of the constituent materials and the volume of the fresh or set concrete as desired. Density is here understood to be the ratio of solids in the concrete to the total volume of the mass. Yield is the volume of concrete resulting from the volume of aggregate mixed as used.

24. *Report.*—The report shall include the following:

(*a*) The kind and origin of concrete materials;

(*b*) Complete data on all tests of cement and aggregates;

(*c*) A description of methods of making and testing the concrete, where methods deviate from the proposed standards;

(*d*) The quantities of cement, aggregates and water in each batch;

(*e*) The method of measuring workability or plasticity with "slump" or "flow" of concrete;

(*f*) The quantity of water expressed as a ratio to volume of cement;

(*g*) The age at test;

(*h*) The size of test specimens;

(*i*) The date of molding and testing each cylinder;

(*j*) The compressive strength in pounds per square inch of each test specimen and the average of tests in a set;

(*k*) A description of failure and appearance of concrete on each test specimen;

(*l*) The unit weight, density and yield of the concrete.

Beam Test

The beam test is made on plain concrete and is intended to measure the strength of the concrete when used in such a manner. Practically all concrete pavements are designed as plain concrete which is not as strong in tension as it is compression. Whatever steel that is used is for the purpose of holding together the con-

crete on either side of a crack or joint. The weakest part of a pavement slab is at a corner formed by the intersection of edges, cracks, or joints. Because of warping, the slab is often up off the subgrade at the corner, which causes the concrete to function as a cantilever beam.

The beam test was developed, therefore, to test pavement concrete because of its direct application. It also has the advantage, as previously mentioned, that it can be made in the field. The apparatus is light and can easily be moved about. Its cost is also low compared to that of the compression machine.

Method of Loading.—The beams are being tested in cantilever in practically every instance. An extension arm is fastened on to the projecting portion so that the load necessary to cause failure is not large. As used, the extension arms are sufficiently long so that the loads need never exceed about 600 lb. The other method of testing is as a simple beam with the load applied either at the middle or third points. The method of loading seems to affect the results, the cantilever method giving the smaller values.

The cantilever method has the advantage over the simple beam method in that more breaks can be secured per beam. Three to four breaks for the same length may be secured in cantilever to one in a simple beam.

Size of Beam.—Beams of various sizes are being used, but the 6 by 6-in. beam is the one most often used. Those larger than this size are too heavy to be handled conveniently and require larger loads to cause failure. A beam 6 in. deep and 4 in. wide has been tried with apparent success. The length will depend upon the number of breaks desired, the length of overhang, and the number of men available for handling. A 12-in. overhang is usually necessary so that the length should be a multiple of 12 in.

Making of Beams.—If beams are being made in the field the procedure outlined previously for compression tests should be followed as much as possible. The concrete should be representative of that being used, the compaction and the curing should be similar to that in use on the job. The beams should be tested at the ages desired. The tests are ordinarily made to determine when the slab is ready to use. In the summer with high air temperatures, the first breaks may be made at 2 or 3 days, with subsequent breaks based on the first ones. After a

few tests have been made a fairly good estimate may be made of the strengths to be expected.

Computations.—The computations necessary in connection with a cantilever test are given here. A knowledge of the prin-

FIG. 110*a*.—One of the first models of the portable transverse testing machines.

ciples of mechanics is necessary to their understanding. See Fig. 111. A concrete beam is fastened on to the support K so that it overhangs a distance o. The weight of the overhanging concrete is P_c. An extension arm is placed on the

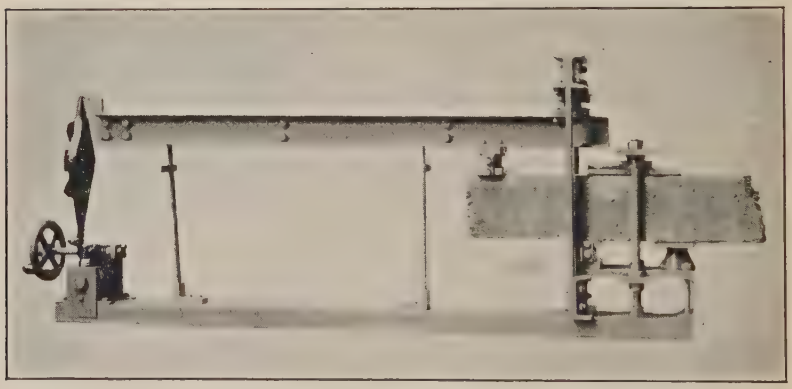


FIG. 110*b*.—The Hercules portable transverse testing machine.

extended concrete. The extension arm weighs P_e and its center of gravity is m distance from the support K. A force P is applied at the end of the extension arm, which is a distance l from the support.

The forces tending to break the beam are:

1. The overhanging concrete.
2. The extension arm.
3. The pull at the end of the extension arm.

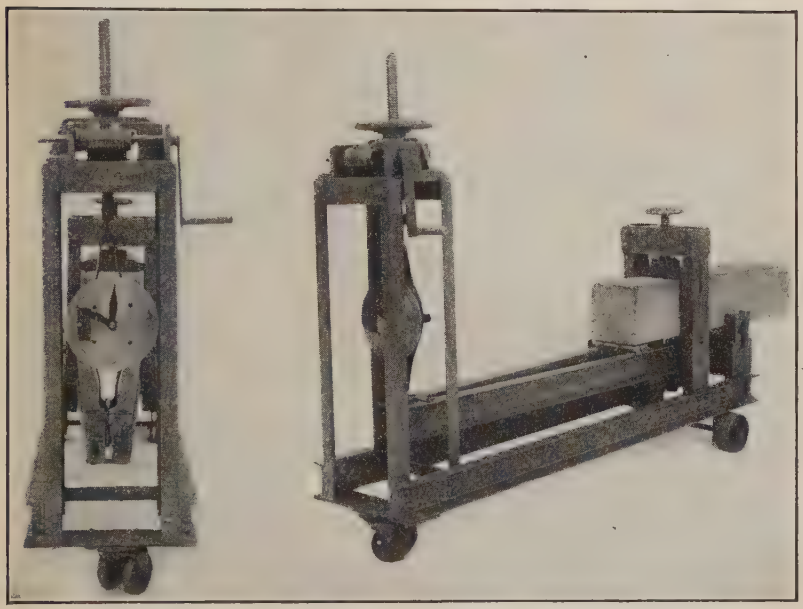


FIG. 110c.—Transverse testing machine designed by the Illinois Division of Highways and used first during construction season of 1928.

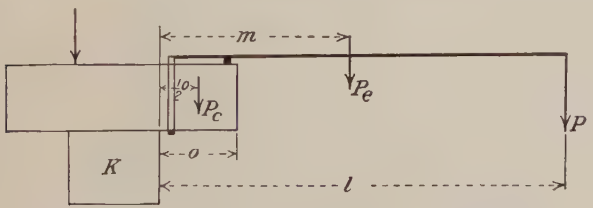


FIG. 111.—Diagram of cantilever test apparatus.

The moment of these forces about the support K are:

1. $P_c \times \frac{1}{2}o$.
2. $P_e \times m$.
3. $P \times l$.

(1) This moment is found by multiplying the weight of the overhanging concrete by one-half the length. (2) The weight and center of gravity of the extension arm and attachments must

be determined. The moment is found by multiplying the weight by the distance the center of gravity is from the support K. (3) The moment of the force applied at the end of the extension arm is equal to that force times the distance to the support K.

The sum of these three moments is known as the *external moment* and is equal to the internal moment which is resisting it. The internal moment is also equal to SI/c in which S is the stress in pounds per square inch at the extreme fibre, I is the moment of inertia of the section ($1/12bd^3$), and c is the distance from the extreme fiber to the neutral axis. Since the two moments are equal, the external moment is also equal to SI/c, in which S is the only unknown.

Example.—Given:
A 6- × 6-in. beam with a 12-in. overhang.
Weight of extension arm is 50 lb.
Center of gravity of extension arm is 25 in. from support.
Distance of force P from support is 48 in.
Force P is 500 lb.
What is the value of S? (This is the modulus of rupture in case of failure.)

External moments:

1. ½ ft. × ½ ft. × 1 ft. × 150 lb. per cubic foot × 6 in =	225 in.-lb.
2. 25 in. × 50 lb =	1,250 in.-lb.
3. 48 in. × 500 lb =	24,000 in.-lb.
Total	25,475 in.-lb.

Moment of inertia:

$$\frac{1}{12}bd^3 = \frac{1}{12} \times 6 \text{ in.} \times 6 \text{ in.}^3 = 108 \text{ in.}^4$$

Distance from extreme fiber to neutral axis:

$$\frac{1}{2} \times 6 \text{ in.} = 3 \text{ in.}$$

From the equation

$$M = \frac{SI}{c}$$

$$25{,}475 \text{ in.-lb.} = \frac{S108 \text{ in.}^4}{3 \text{ in.}}$$

$$S = 708 \text{ lb. per square inch}$$

The beam test has not been fully developed yet (1928). The view in Fig. 110*a* shows one of the first portable machines. It seemed that there was some restraint due to the method of applying the extension arm. The type shown in 110*b* was developed to overcome the objection to the first one. The machine shown in Fig. 110*c* was developed by the Illinois Division of Highways following a thorough study of all the other types in use. One item that still needs attention is the horizontal distance between the points which hold the beam (d, in Fig. 111) and, also,

the horizontal distance between the support and the point of application of the load. These distances undoubtedly should be greater than the depth of the beam, in order to eliminate any shearing action.

Relation between Beam and Compressive Strengths.—There is only a general relationship between beam and compressive strengths. Modulii of rupture are approximately 20 per cent of the compressive strength of corresponding test cylinders. For any given set of materials, beam and compressive strengths will

FIG. 112.—Making slump test. *Left*, molding. *Right*, measuring amount of slump.

vary in the same way due to any of the factors which affect strength. Recent tests in New Jersey showed that for the materials used, the crushed stone concrete gave higher beam strengths than did pebble concrete for the same crushing strengths in cylinders. The crushed stone used was New Jersey trap rock, while the pebbles were unusually smooth. Limestone and ordinary pebbles do not show any differences in the beam test results for the same values of compressive strength. Until more information is secured, too much dependence should not be placed on the general ratio of 1:5 between beam and compressive strengths.

CONSISTENCY TESTS

There are two consistency tests now in general use: the slump test and the flow test. The former may be used either in the laboratory or in the field, while the latter, because of the size of

the apparatus, is limited to laboratory use only. There is no direct relationship between the results of the two tests, so that the value for one test can not be estimated from the value for the other one. Both tests are limited in their use. The chief use

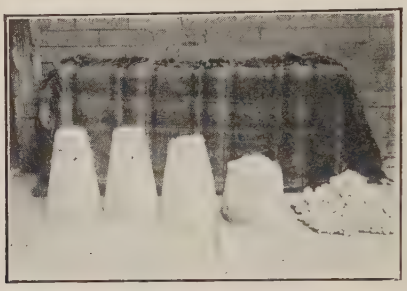


FIG. 113.—Slump test specimens which have been allowed to harden and which may be kept on exhibit.

for them is in the control of the amount of mixing water being used in the field.

Flow Test.—The directions for the making of flow test are given in the *Standard Methods of Making Compression Tests of*

FIG. 114.—Flow test.

Left, concrete is molded in truncated cone on the top of the flow table. After the form is removed the table top is raised and lowered 15 times in 10 seconds by means of crank and cam.

Right, concrete after the test. The diameter of the concrete is determined and the flow is expressed as a percentage in terms of the original diameter.

Concrete, quoted previously in this chapter on page 230, and the reader is referred there for them.

Slump Test.—The directions for making the slump test are those of the American Society for Testing Materials as given in their *Tentative Method of Test for Consistency of Portland-Cement Concrete* (Serial Designation D138-26T).

Tentative Method of Test for Consistency of Portland-cement Concrete

Serial Designation D138-26T

1. *Scope*—This test covers the method to be used both in the laboratory and in the field for determining consistency of concrete.[1]

2. *Apparatus.*—The test specimen shall be formed in a mold of No. 16 gage galvanized metal in the form of the lateral surface of the

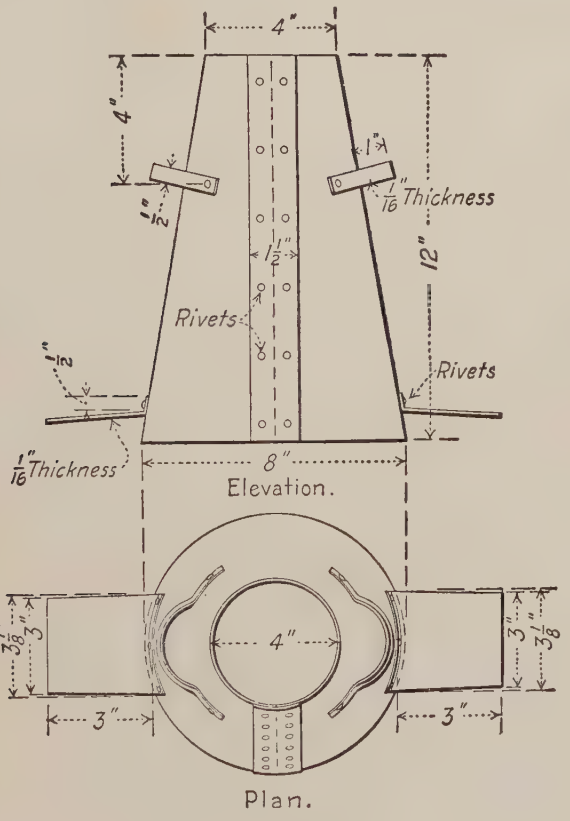


Fig. 115.—Slump cone.

frustrum of a cone with the base 8 in. in diameter, the upper surface 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the

[1] This test is not considered applicable when there is a considerable amount of coarse aggregate over 2 in. in size in the concrete. The committee is now working on a method suitable for determining the consistency of concrete using aggregate over 2 in. in size.

cone. The mold shall be provided with foot pieces and handles as shown in Fig. 115.

3. *Sample.*—When the test is made at the mixer, the sample shall be taken from the pile of concrete immediately after the entire batch has been discharged. When testing concrete that has been hauled from a central mixing plant, the sample shall be taken from the concrete immediately after it has been dumped on the subgrade.

4. *Procedure.*—The mold shall be placed on a flat, non-absorbent surface, such as a smooth plank or a slab of concrete, and the operator shall hold the form firmly in place, while it is being filled, by standing on the foot pieces. The mold shall be filled to about one-fourth of its height with the concrete which shall then be puddled, using 25 strokes of a $\frac{5}{8}$-in. rod, 2 ft. long, bullet pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then be removed by being raised vertically, immediately after being filled. The molded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

5. *Slump.*—The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump.

$$\text{Slump} = 12 - \text{inches of height after subsidence}$$

Questions

1. Compare the beam and compression tests for concrete.
2. What size of specimen is used for the compression test? What is the ratio between diameter and length?
3. Describe the method of mixing concrete by hand.
4. Describe slump test. In what terms is the slump value given?
5. Describe flow test. Flow value is given in what terms?
6. Describe method of capping cylinders. Why should a machined plate be used in preference to a piece of rolled plate?
7. How may the concrete specimens be cured? What is the temperature range permitted?
8. At what age is concrete usually tested? At what other ages are tests made?
9. Why should the cylinders be tested while damp?
10. Describe method of testing cylinders.
11. What is the most common size (cross-section) of beam used?
12. Concrete is being tested in the machine shown in the lower view of Fig. 110*b*. The beam is 6- × 6 in. in cross section. The distance from the support to the dynamometer is 36 in. The concrete overhangs 10 in. The effect of the extension arm is equivalent to a pull of 25 lb. on the dynamometer. Figure the modulus of rupture when the dynamometer reading is 400 lb. to cause failure.

INSTRUCTIONS FOR THE PERFORMANCE OF LABORATORY TESTS

On the following pages are given instructions for the performance of the various tests on concrete materials and for a number of concrete research problems suitable for class work. The methods outlined are in accordance with those prescribed by the American Society for Testing Materials, except in cases where this society has not prepared standard or tentative standard methods. The method followed is indicated under the title in each case.

TEST NO. 1

DETERMINATION OF SPECIFIC GRAVITY OF PORTLAND CEMENT[1]

Outlined in accordance with A. S. T. M. specification, serial designation C9-21. This test was eliminated in the 1926 revision of the specification.

Purpose

1. To determine the weight per unit solid volume of the cement particles. Specific gravity should be distinguished from weight per unit of bulk volume.

Apparatus

Balance
Le Chatelier flask
Glass rod 6 to 8 in. long

Materials

Kerosene free from water
Or benzene not lighter than 62°Bé.

Method

2. All equipment and materials should be at practically the same temperature before starting the test. For this purpose, 12 to 24 hours should be a sufficient length of time.

3. Fill the flask with either liquid to a point on the stem between 0 and 1 cc. Note the reading.

4. Immerse the flask in water during the following operation. The temperature of the water should be at room temperature, which should be approximately 21°C. (70°F.). The variation in temperature should not exceed 0.5°C. during the test.

5. It has been the experience of the writer that there is less difficulty when the immersion in water is omitted. The air temperature in the laboratory ordinarily does not change rapidly enough to cause any difficulty. Handling of the flask should be kept at a minimum.

6. Introduce 64 g. of the cement into the flask slowly, being careful not to have any of the cement adhere to the inside of the flask above the liquid. Difficulty will be experienced as the liquid rises into the bulb and as the liquid just fills the bulb. Roll the flask in an inclined position to free air from the cement. After all the cement is in, the level of the liquid will rise to some division of the graduated neck. The difference between the readings is the volume displaced by 64 g. of cement.

7. Clean out the flask immediately upon the completion of the test. Do not use any water. Should any of the cement stick in the flask, it may be easily removed by heating in an oven at a temperature of approximately 100°C.

[1] Applicable to any hydraulic cement.

8. *Testing an Ignited Sample.*—In case the sample fails to pass as received, a retest may be made on an ignited sample. The sample may be ignited in a platinum crucible in either of the following ways:

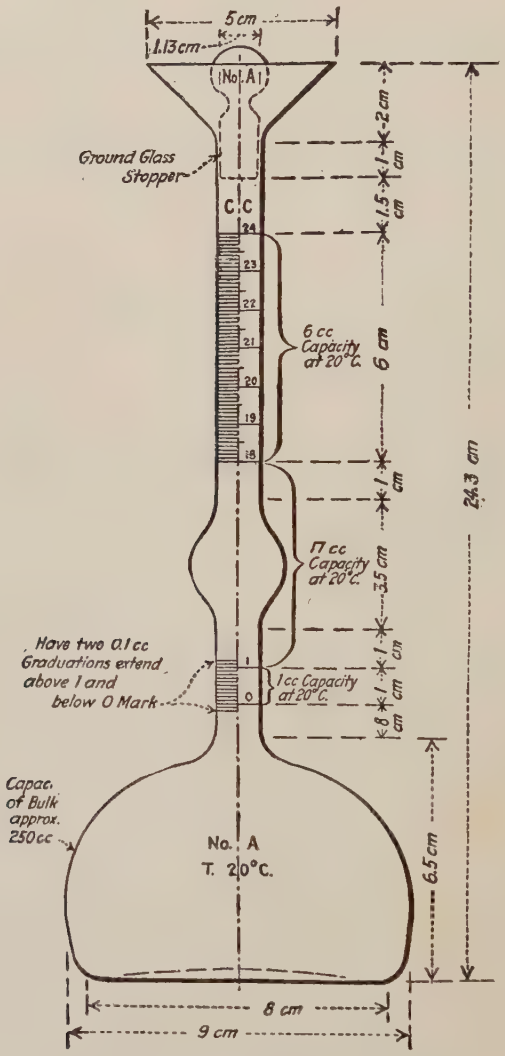


FIG. 1.—Le Chatelier specific gravity flask.

a. Place the platinum crucible in a hole in an asbestos board, clamped horizontally so that about three-fifths of the crucible projects below. Blast at a full red heat for 15 min. with an inclined flame.

b. Place the platinum crucible in a muffle furnace at any temperature between 900 and 1,000°C. for 15 min.

Questions

1. Of what value is the specific gravity test for portland cement?
2. What was the old requirement in the standard specifications?
3. Considering a bag of cement as 1 cu. ft., what is the percentage of voids in cement?

DATA RECORD—TEST NO. 1

SPECIFIC GRAVITY OF PORTLAND CEMENT

Material		Lehigh
Date		2/7/30
Air temperature		78° F
Weight of cement used		64 g
Initial reading of flask		0.60
Final reading of flask		20.1
Volume of cement particles		19.5
Specific gravity		3.28

TEST NO. 2

DETERMINATION OF FINENESS OF PORTLAND CEMENT

A. S. T. M. Serial Designation C9-26

Purpose

1. To determine the fineness of grinding of a cement. This is measured in terms of the percentage of the cement retained on a standard 200-mesh sieve.

Apparatus

Balance
200-mesh sieve, pan, and cover
Machine shaker

Specifications for Apparatus

2. *Sieve.*—Wire cloth for standard sieves for cement shall be woven (not twilled) from brass, bronze, or other suitable wire, and mounted without distortion on frames about 2 in. below the top of the frame. The joint between the cloth and frame shall be smoothly filled with solder to prevent lodging of the cement. The sieve frames shall be circular, approximately 8 in. in diameter, and may be provided with a pan and cover.

A standard No. 200 sieve is one having nominally a 0.0029-in. opening, certified by the U. S. Bureau of Standards, and conforming to the specifications for this sieve in the Standard Specifications for Sieves for Testing Purposes, serial designation E11, of the A. S. T. M. The correction to the sieving value of the sieve shall be determined by sieving tests made in conformity with the standard specifications for these tests on a standardized cement which gives a residue of about 20 per cent on the No. 200 sieve.

3. *Balance.*—The balance should give results correct within 5 mg. and be sufficiently sensitive so that the rest point will be deflected at least two divisions of the scale for an added load of 5 mg.

Method

4. The specifications require hand shaking and permit machine shaking under one condition. Samples failing with machine testing must be retested by hand shaking before the shipment may be rejected. Machine shaking is becoming more and more general. The advantages are: (1) It is possible to run a large number of samples at one time; and (2) results of machine shaking are not so variable as the results of hand shaking.

5. *Preparation of the Sample.*—Weigh out 50 g. of the cement to be tested.

6. *Testing the Sample. Hand Shaking.*—Place the sample on the sieve with the pan in place. Cover and shake as follows:

7. Hold the outfit in one hand in an inclined position. Move the hand with the sieve back and forth in an inclined direction, tapping the side of the sieve with the other hand on the up stroke at the rate of 150 times per minute. Every twenty-fifth stroke turn the sieve one-sixth revolution.

8. After several minutes of continuous shaking, weigh the cement in the pan. For 1 min. more, shake the material remaining on the sieve. Determine the weight of material passing in the minute of shaking. Continue shaking for 1-min. intervals and determine the weight passing each time until not more than 0.05 g. passes in 1 min. of continuous shaking.

9. The percentage of residue on the sieve, when the point is reached where not more than 0.05 g. passes in 1 min. of continuous shaking, expresses the fineness of the cement.

10. *Machine Shaking.*—Shake the sample of cement in the machine shaker for 15 min. Weigh the residue on the 200-mesh sieve. Do not use any washers, shot, or slugs on the sieve. Machine shaking may give results different from hand shaking. A correction factor should be determined for each machine and the length of shaking used.

11. *Retesting.*—Should the cement as received fail to pass this test, retest, using a sample which has been dried for 1 hour at a temperature of 100°C. The retest result shall be used. Excessive humidity interferes with good sieving. It tends to decrease the percentage of cement passing the sieve and, in general, to produce irregular results.

12. NOTE.—Certain sieve manufacturers supply certified sieves with a correction factor determined by the U. S. Bureau of Standards, Washington, D. C. Sieves vary somewhat in the number and size of openings and will give different results even though they may come within the required specification. Sieves having a correction factor of more than 3 per cent should not be used. An occasional redetermination of the correction is desirable as an indication of the satisfactory condition of the sieve.

For the benefit of those who wish to determine the correction factors of their sieves the Bureau of Standards furnishes samples of cement of standard fineness at 50 cts. each. These samples are mailed in sealed glass bottles containing about 160 g. of cement and are guaranteed to be within 0. 2 per cent of the true fineness as determined on the Bureau's standard sieves. A more general use of standard fineness samples is recommended, not only for determining corrections to sieves, but also for checking the performance of operators and for preparing and standardizing auxiliary fineness samples for use in the laboratory.[1]

[1] From *Laboratory Manual of Cement Testing*, prepared by Committee C-1 on Cement and accepted by the A. S. T. M. for publication as information with the standard specifications. The manual is not a part of the specifications.

Questions

1. What is the effect of additional fineness of grinding upon the compressive strength of mortar and concrete?

2. What is the specification requirement for this test? If the cement fails to pass as received, what provision is made?

3. How many openings per square inch in a 200-mesh sieve?

DATA RECORD—TEST NO. 2

FINENESS OF PORTLAND CEMENT

Material		
Date		
Air temperature		
Weight of sample used		
Method of shaking		
Weight retained on 200-mesh sieve		
Per cent retained		

TEST NO. 3

DETERMINATION OF NORMAL CONSISTENCY OF PORTLAND CEMENT

A. S. T. M. Serial Designation C9-26

Purpose

1. To determine the proper amount of mixing water to make a cement paste of a given consistency. The cement paste is of normal consistency when the Vicat needle penetrates 10 mm. in 30 sec. In making the soundness and time-of-set tests, cement paste of normal consistency is used. In making the tension test the amount of mixing water used in making the mortar is based on the water required for normal consistency.

Apparatus

Pan, beaker, trowel, graduate
Vicat apparatus
Conical ring
Seconds clock or watch
Balance
Glass plate 10 cm. square
Rubber gloves

Specifications for Apparatus

2. *Vicat Apparatus.*—The Vicat apparatus consists of a frame *A* (Fig. 1) bearing a movable rod *B*, weighing 300 g., one end *C* being 1 cm. in diameter for a distance of 6 cm., the other having a removable needle *D*, 1 mm. in diameter, 6 cm. long. The rod is reversible, can be held in any

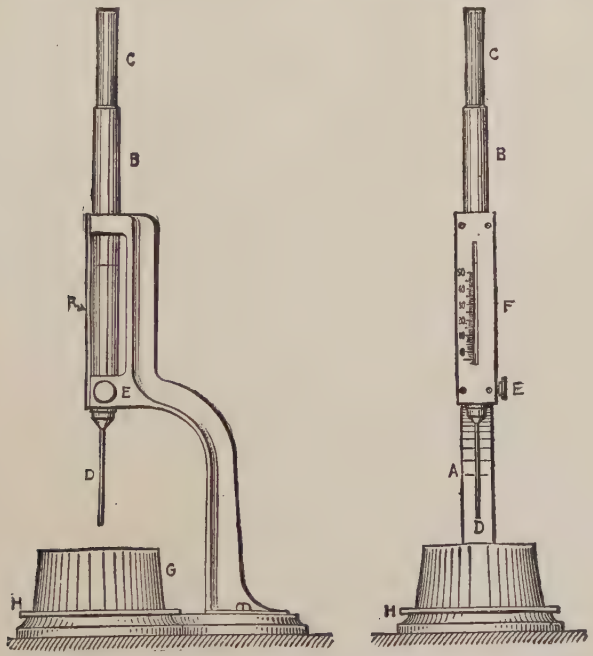


FIG. 1.—Vicat apparatus. The rod *B* should be reversed for normal consistency determination. Needle *C* should be used. Needle *D* is for time of setting test.

desired position by a screw *E*, and has, midway between the ends, a mark *F* which moves under a scale (graduated to millimeters) attached to the frame *A*. The paste is held in a rigid conical ring, resting on a glass plate about 10 cm. square. The ring shall be made of a non-corroding, non-absorbent material, and shall have an inside diameter of 7 cm. at the base and 6 cm. at the top, and a height of 4 cm.

Method[1]

3. The determination of the proper amount of mixing water for normal consistency is a cut-and-try process, several trials ordinarily being necessary. The percentage of water for normal consistency of most cements lies between 21 and 28 per cent. The first trial should be made using 24 per cent. Other trials should be based on the first or subsequent trials.

4. Occasionally a cement will be found which will stiffen considerably during the first few minutes in the ring. Difficulty will then be experienced in securing a satisfactory result.

5. The temperature of the room and materials should be 21°C. (70°F.), and must be maintained at that temperature within 3°C. (5°F.).

6. *Preparation of the Sample.*—Mix 500 g. of cement with 24 per cent by weight of water in the following manner:

7. Place the cement on a non-absorbent surface, which has been moistened. Form a crater and pour the water into it. Turn the material on the outer edge toward the center with the trowel.

8. During the following steps the hands should be protected with rubber gloves. After an interval of ½ min. for the absorption of the water, complete the operation by continuous vigorous mixing, squeezing, and kneading with the hands for at least 1 min. It is better to have the paste overmixed than undermixed.

9. Form the paste quickly into a ball with the hands. Maintaining the hands about 6 in. apart, toss the ball six times from one hand to the other.

10. In the following operation take care not to compress the paste. With the ball resting in the palm of one hand, press the paste into the larger end of the ring held in the other hand. Fill the ring completely with the paste. Remove the excess paste at the larger end by a single movement of the hand. Place the ring with the paste on a glass plate. Remove excess paste at smaller end by a single oblique stroke of the trowel held at a slight angle with the top of the ring. Smooth the top, if necessary, with a few light touches of the pointed end of the trowel. Do not puddle surface.

11. *Testing the Sample.*—Test the sample immediately in the Vicat apparatus. Be sure that the plunger is clean and moves freely in the guides and that there are no vibrations. Place the sample under the plunger. The larger end should be down. Bring the plunger into contact with the surface of the paste. Release the plunger for 30 sec. and note the amount of settlement.

12. The paste is of normal consistency when the plunger settles 10 mm. in 30 sec. If the first trial does not give the desired 10-mm. pene-

[1] See manual of cement testing which is published by Committee C9, as a supplement, but not as a part of, the standard specifications and tests.

tration, repeat test using new batch of cement but with a different amount of mixing water. Repeat until the desired consistency is secured.

Questions

1. What items in the procedure in this test will affect the normal consistency result?
2. What is the range of normal consistencies for most portland cements?
3. Is this a test for quality of the cement? What is the purpose of the test?

DATA RECORD—TEST NO. 3

TEST FOR NORMAL CONSISTENCEY OF PORTLAND CEMENT

Material			[illegible]
Date			2/7/30
Air temperature			70° F
Weight of cement used			[illegible]
Trial No. 1	Per cent water used		24
	Penetration mm.		6
Trial No. 2	Per cent water used		25
	Penetration		9
Trial No. 3	Per cent water used		25
	Penetration		9
Trial No. 4	Per cent water used		
	Penetration		
Trial No. 5	Per cent water used		
	Penetration		
Normal consistency occurs at			25%

TEST NO. 4

DETERMINATION OF SOUNDNESS OF PORTLAND CEMENT

A. S. T. M. Serial Designation C9-26

Purpose

1. To determine whether a cement is sound or not.

Apparatus

Pan, beaker, trowel, and graduate
Balance
Glass plate 4 in. square
Moist closet
Steam bath

Specifications for Apparatus

2. *Steam Bath.*—A steam apparatus, which can be maintained at a temperature between 98 and 100°C., or one similar to that shown in

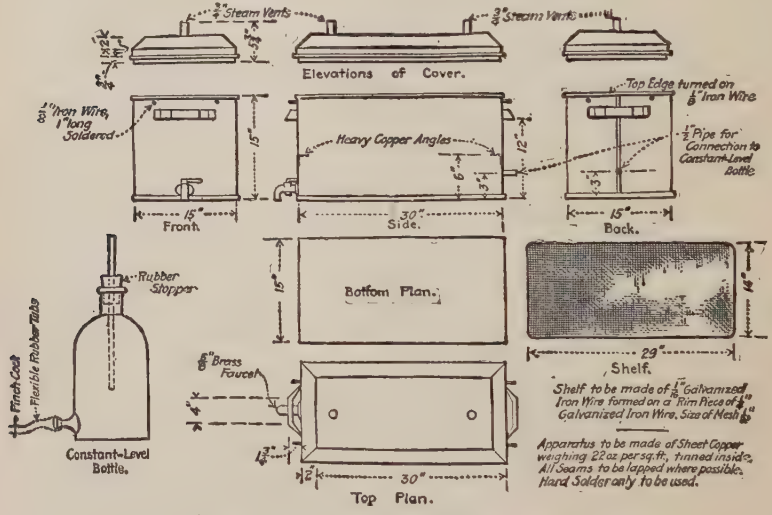
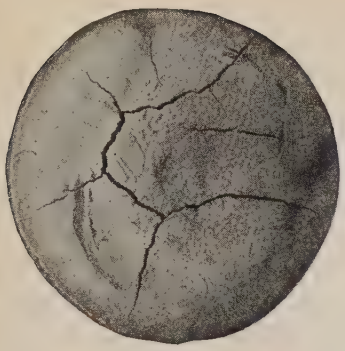


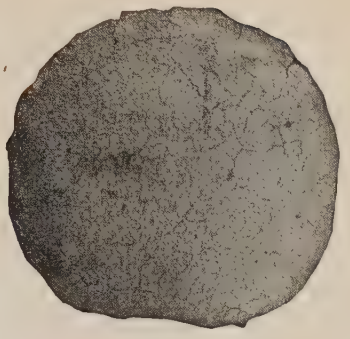
FIG 1.—Apparatus for making soundness test of cement.

Fig. 1, is recommended. The capacity of this apparatus may be increased by using a rack for holding the pats in a vertical or inclined position.

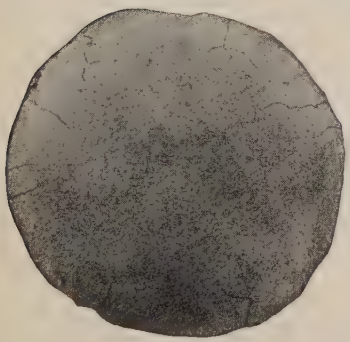
3. *Moist Closet.*—The moist closet may consist of a soapstone, slate or concrete box, or a wooden box lined with metal. The interior wall surfaces of all closets shall be covered with felt or broad wicking kept wet. The bottom of the moist closet shall be covered with water to a depth of at least 2 in.



Shrinkage

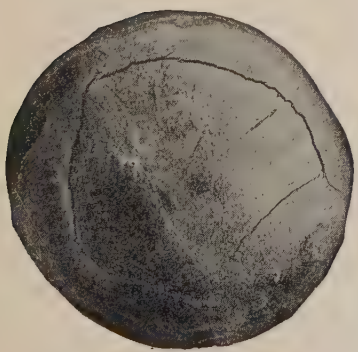


Checking

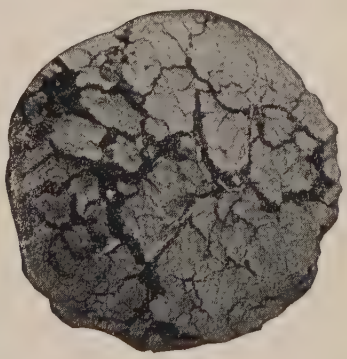


Cracking

Distortion



Shrinkage



Disintegration

FIG. 2.—Typical failures in soundness test.

Method

4. *Preparation of the Specimen.*[1]—Make up a paste of normal consistency, as described in the test for the determination of normal consistency, using 500 g. of cement.

5. Mold on the glass plate a pat 3 in. in diameter and ½ in. thick at the center, and tapering out to a thin edge. In molding the pat, flatten the cement paste first on the glass plate and then form by drawing the trowel from the outer edge toward the center. The edge of the pat should be clearly defined on the glass plate.

6. Place the pat immediately in the moist closet, where it is to remain for 24 hours. The pat should be marked for identification later on.

7. *Testing the Specimen.*—At the end of 24 hours in the moist closet, place the pat in the steam bath for 5 hours. The temperature of the steam bath should be between 98 and 100°C. The pats should be 1 in. above the water.

8. Examine the pat. A sound cement will retain its shape with no distortion, cracking, checking, or disintegration. Pats improperly made or exposed to drying may develop what are known as shrinkage cracks within the first 24 hours and which are not an indication of unsoundness. These conditions are illustrated in Fig. 2.

9. *Retesting.*—The cement is first tested as it is received. If it fails to pass this test, a retest may be made on another sample taken any time within 28 days. If the retest result is satisfactory, the cement may be used.

10. The provision for retesting appears only in A. S. T. M. standard, both old and new. The American Association of State Highway Officials have not included it in their specifications as given in *Bulletin* 1216, of the U. S. Department of Agriculture.

Questions

1. Describe the procedure in the performance of this test.
2. What is likely to cause unsoundness in portland cement?
3. Why is it necessary to keep the cement paste moist in this test while it is setting?
4. What provision is made in the specification should the cement fail to pass as received?

[1] The new A. S. T. M. specifications C9-26 permit the use of the pat made for the time of setting test.

DATA RECORD—TEST NO. 4

DETERMINATION OF SOUNDNESS OF PORTLAND CEMENT

Material	C.P.C.	
Date	9/1/26	
Air temperature	26°C.	
Weight of cement used	500 gr.	
Weight of water used	125 cc.	
Time when mixed	1:50	
Time placed in moist closet		
Time placed in steam bath		
Time removed from steam bath		
Interval in moist closet	5 days.	24 Hrs.
Interval in steam bath	5 Hrs.	5 Hrs.
Condition of pat	Good.	

If unsound, give evidences of unsoundness:

TEST NO. 5

DETERMINATION OF THE TIME OF SETTING OF PORTLAND CEMENT

A. S. T. M. Serial Designation C9-26

Purpose

1. To determine the rate of setting of a neat cement paste. For purposes of testing, this is determined at two arbitrary points: the first known as initial set and the second as final set.

Apparatus

Pan, beaker, trowel, and graduate
Balance
Moist closet
Method A:
  Glass plate 4 in. square
  Gillmore needles
Method B:
  Vicat apparatus
  Conical ring
  Glass plate 4 in. square

Specifications for Apparatus

2. *Vicat Apparatus.*—The Vicat apparatus used in this test is the same as that prescribed for the test for the determination of normal consistency (see Fig. 1, Test No. 3).

Gillmore Needles.—The Gillmore needles should preferably be mounted as shown in Fig. 1, and the needle ends shall be maintained in a clean condition and shall be plane and at right angles to the axis of the rod.

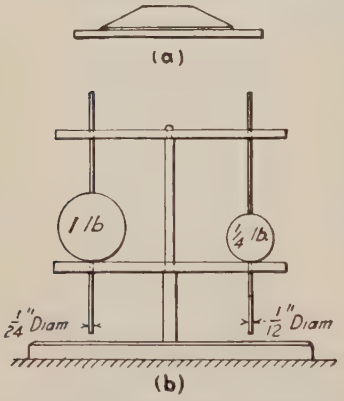


FIG 1.—(*a*) Pat with top surface flattened for determining time of setting by Gillmore method. (*b*) Gillmore needles.

3. *Moist Closet.*—The moist closet may consist of a soapstone, slate, or, concrete box, or a wooden box lined with metal. The interior wall surfaces of all closets shall be covered with felt or broad wicking kept wet. The bottom of the moist closet shall be covered with water to a depth of at least 2 in.

Method

4. There are two methods for determining the time of setting. One uses a pat similar to the soundness pat, but flattened on top, and the Gillmore needles. The other uses a specimen molded in the conical ring, and the Vicat apparatus as in the determination for normal consistency, but with a different diameter of needle.

Method A with Gillmore Needles

5. *Preparation of the Specimen.*—Prepare a paste of normal consistency, using 500 g. of cement. Note the clock time when mixing was started. Mold the pat similar to one for soundness test and then flatten the top with the trowel. An area 1 in. in diameter is sufficient.

6. *Care of the Specimen.*—Place the pat in moist closet immediately after molding.

7. *Testing the Specimen.*—The cement has taken its initial set when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{12}$ in. in diameter and loaded to weigh $\frac{1}{4}$ lb. The final set has taken place when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{24}$ in. in diameter and loaded to weigh 1 lb. The specifications provide that initial set shall not take place in less than 1 hour, and the final set shall be within 10 hours. In order to tell whether the cement meets this specification, it is necessary to begin testing before 1 hour.

8. At the end of 45 min., make a first trial for initial set. Place the pat under the $\frac{1}{4}$-lb. needle, bring the needle in contact with the surface of the pat, and release. If the needle penetrates into the pat, initial set has not taken place. Return the pat to the moist closet and repeat the test at intervals sufficiently close so that there may be no doubt about the result. The interval for the beginner ought not be greater than 10 min. nor less than 5 min. Repeat the test until initial set is determined. Note the clock time. The interval since mixing is known as initial set.

9. For final set, use the 1-lb. needle. The intervals between trials should be based on the penetration of the needle. As the penetration becomes less, the interval should be shortened. The final set should occur within 10 hours.

Method B with Vicat Apparatus

10. *Preparation of the Specimen.*—Prepare a paste of normal consistency, using 500 g. of cement. Mold the paste in a ring as in the determination of normal consistency.

11. *Care of the Specimen.*—Place the specimen in a moist closet immediately after molding.

12. *Testing the Specimen.*—Initial set occurs when the Vicat needle (smaller end) ceases to penetrate past a point 5 mm. above the glass upon which the paste is resting. This should not occur in less than 45 min. Final set takes place when the needle does not penetrate the surface. This should take place within 10 hours.

13. At the end of 35 min. remove the specimen from the moist closet. Place on the Vicat apparatus and bring the needle into contact with the surface of the paste. Release the plunger for 30 sec. Note the reading of the scale. Push the needle down to make contact with the glass and read the scale. When the difference is 5 mm., initial set has taken place.

14. After a reasonable interval, try for final set. The exact interval will vary with different cements. From 1 to 1½ hours is generally a safe length of interval before trying for final set after initial set has taken place.

Questions

1. How is the rate of setting of portland cement controlled in the manufacturing process?

2. What are the specification requirements for this test?

3. What is the difference in meaning of the two words "setting," and "hardening?" What is meant by a "fast-hardening cement?"

DATA RECORD—TEST NO. 5

DETERMINATION OF TIME OF SETTING OF PORTLAND CEMENT

Material			
Date			
Air temperature			
Weight of cement used			
Weight of water used			
Clock time at beginning of mixing operation			
Gillmore needles	Initial set	Clock time	10:30
		Interval	
	Final set	Clock time	
		Interval	
Vicat needle	Initial set	Clock time	10 AM
		Interval	1hr 25m
	Final set	Clock time	
		Interval	

TEST NO. 6

TENSION TESTS OF PORTLAND CEMENT

A. S. T. M. Serial Designation C9-26

Purpose

1. To determine the tensile strength of the cement as measured by the strength of a mortar composed of the cement and standard Ottawa sand. The ages at testing are 7 and 28 days.

Apparatus

Pan, beaker, trowel, and graduate
Balance
Two three-gang briquet molds
Three glass plates, approximately 3 × 12 in.
Water storage tank
Moist closet
Briquet testing machine.

Specifications for Apparatus

2. *Molds.*—The form of test piece shown in Fig. 1 shall be used. The molds shall be made of non-corroding metal and have sufficient material in the sides to prevent spreading during molding. Gang molds, when used, shall be of the type shown in Fig. 2. Molds shall be oiled with a mineral oil.

3. *Testing Machine.*—The machine shall be capable of weighing the applied load within 0.5 per cent of the nominal value. The sensibility reciprocal (the weight required to be added to the load to move the beam from a horizontal position of equilibrium to a position of equilibrium at the top of the trig loop) shall not exceed 1 lb. at the full capacity of the machine or at any lesser load. The clips for holding the tension test pieces shall be in accordance with Fig. 3.

4. *Moist Closet.*—The moist closet may consist of a soapstone, slate, or concrete box, or a wooden box lined with metal. The interior wall surfaces of all closets shall be covered with felt or broad wicking kept wet. The bottom of the moist closet shall be covered with water to a depth of at least 2 in.

Material

Standard Ottawa Sand

5. *Specification for Material.*—The sand shall be natural sand from Ottawa, Illinois, screened to pass a No. 20 sieve and retained on a No. 30 sieve. This sand may be obtained from the Ottawa Silica Company, Ottawa, Illinois.

This sand shall be considered standard when not more than 5 g. are retained on the No. 20 sieve, and not more than 5 g. pass the No. 30 sieve, after 1 min. of continuous sieving of a 100-g. sample, in the manner specified for sieving cement on the No. 200 sieve.

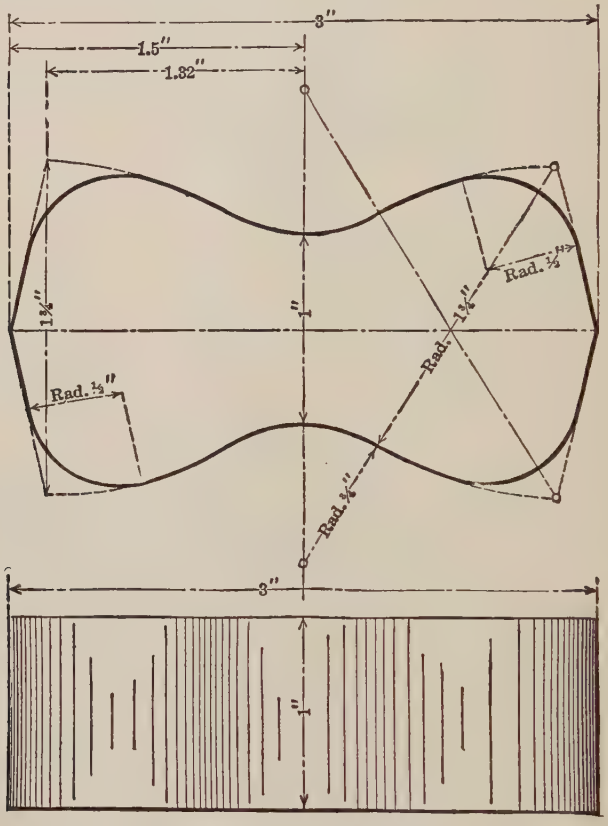


FIG. 1.—Details for briquet.

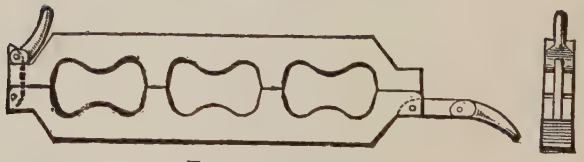
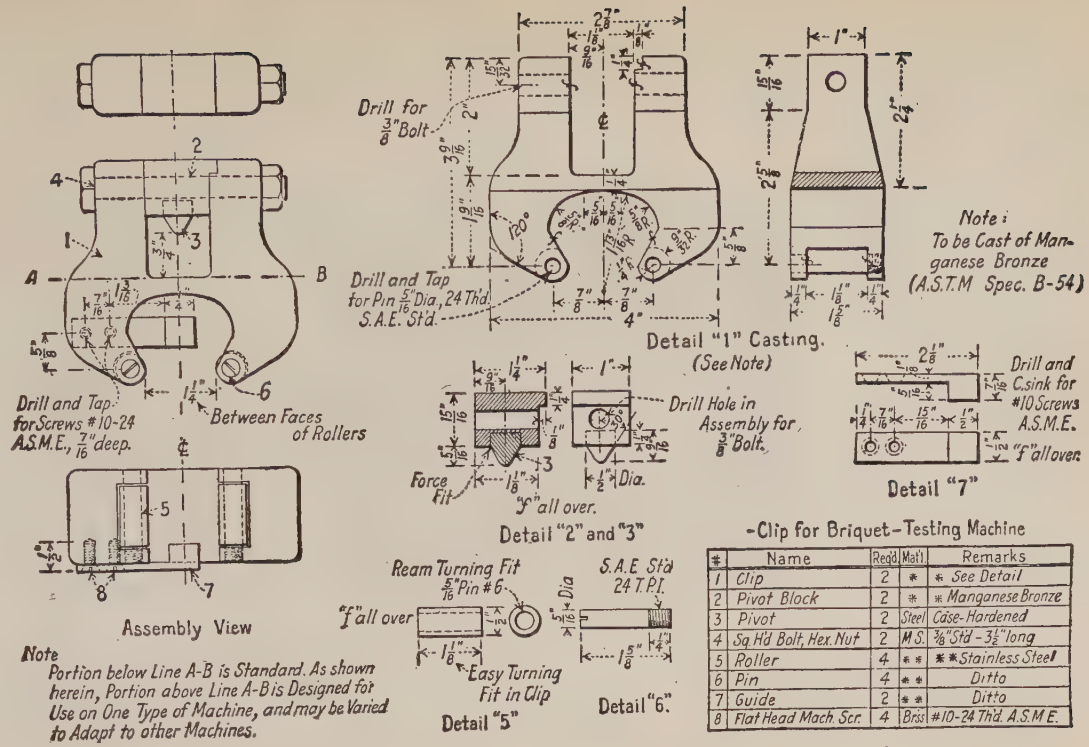


FIG. 2.—Gang mold.

The Nos. 20 and 30 sieves shall conform to the requirements for these sieves as given in the "Standard Specifications for Sieves for Testing Purposes," serial designation E11.



Clip for Briquet-Testing Machine

#	Name	Reqd.	Mat'l.	Remarks
1	Clip	2	*	* See Detail
2	Pivot Block	2	*	* Manganese Bronze
3	Pivot	2	Steel	Case-Hardened
4	Sq. Hd. Bolt, Hex. Nut	2	M.S.	3/8" Std - 3 1/2" long
5	Roller	4	* *	* * Stainless Steel
6	Pin	4	* *	Ditto
7	Guide	2	* *	Ditto
8	Flat Head Mach. Scr.	4	Brass	#10-24 Thd. A.S.M.E.

FIG. 3.—Clip for briquet-testing machine.

Method

6. The specifications require that the reported tensile strength for either age shall be the average of at least three specimens. Results from specimens which are obviously faulty or results which vary more than 15 per cent from the average of all specimens are not to be included. An experienced tester can ordinarily make a set of specimens which will test within a range of 10 lb. The writer feels that if a set of specimens is made which does not agree within 15 per cent of the average of the set, the test should be repeated, rather than eliminate those without the range and use the average of the rest. Three specimens then should be sufficient.

FIG. 4.—A type of briquet testing machine with the new style A. S. T. M. clips.

7. *Preparations of Specimens.*—Clean the molds with a wire brush and oil them with a mineral oil. Place the molds on the glass plates.

8. Mix a batch of 250 g. of cement and 750 g. of standard Ottawa sand. The method of mixing is the same as that given in the test for the determination of normal consistency. The percentage of water to be used is dependent upon the percentage of water necessary to produce a paste of normal consistency, and is taken from Table 1, Percentages of Water for Standard Mortars. The percentage given in the table is expressed as a percentage of the combined weight of the cement and sand.

9. Mold the specimens immediately following mixing. The following method is that of the new A. S. T. M. specification C9-26, and does not conflict with the former specification, C9-21. The new specification gives the procedure in greater detail. Fill the molds heaping full without compacting. Then press in the mortar firmly with the thumbs,

TABLE 1.—PERCENTAGES OF WATER FOR STANDARD MORTARS

Percentage of water for neat cement paste of normal consistency	Percentage of water for 1 part cement, 3 parts standard Ottawa sand	Percentage of water for neat cement paste of normal consistency	Percentage of water for 1 part cement, 3 parts standard Ottawa sand
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

applying pressure twelve times to each briquet, at points to include the entire surface. The pressure shall be such that the simultaneous application of both thumbs will register a pressure of between 15 and 20 lb. Each application of the thumbs shall be maintained no longer than is necessary to attain the specified pressure. Heap the mortar above the molds and smooth off with a trowel. The trowel shall be drawn over the mold in such a manner as to exert a pressure of not more than 4 lb. Turn the mold over upon a plane plate oiled with mineral oil, and repeat the operation of heaping, thumbing, and smoothing. Do not ram, or tamp, or trowel in excess of that required to smooth off the specimen.

10. *Care of Specimens.*—Immediately following molding, place the specimens in the moist closet in such a way that the upper surface is exposed to the moist air.

After 20 to 24 hours in the moist closet, remove the specimens from the moist closet and the molds, and store in a water tank until tested. The specifications provide that the temperature of the room, the materials, the mixing water, the air in the moist closet, and the water in the storage tanks shall be maintained as nearly as possible at 21°C. (70°F.), and with the exception of the first two must be maintained within 3°C. (5°F.) of that temperature. Temperature during curing affects the strength.

11. *Testing the Specimens.*—At the end of 7 days, remove the specimens to be tested at 7 days and test immediately following removal. The bearing surfaces of the clips and briquets shall be free from sand or dirt, and the roller bearings shall be well oiled and maintained so as to insure freedom of turning. Center the briquets carefully in the clips and apply the load continuously at the rate of 600 lb. per minute.

12. Repeat the test at 28 days on the 28-day specimens.

Questions

1. What are the specification requirements for this test?
2. Describe briefly this test.
3. What are the sieve requirements for the standard Ottawa sand?
4. A cement fails to pass at 7 days but does pass at 28 days. What would you think about accepting it?

DATA RECORD—TEST NO. 6

TENSION TESTS OF PORTLAND CEMENT

Material			U. P. C	Lehigh
Date			10/1/26	2/14/30
Air temperature			26° C.	75° F
Weight of cement used			250 g	250 g
Weight of standard Ottawa sand used			750 g	750 g
Weight of water used			107 g	107 g
Test results lb. in 2	7 days	1	180	210
		2	200	185
		3	230	195
		Average	210	196.6
	28 days	1		
		2		
		3		
		Average		
Specification requirements	7 days		225	
	28 days		325	

TEST NO. 7

COMPRESSION TESTS OF PORTLAND CEMENT

A. S. T. M. Serial Designation C9-16T

Purpose

1. To determine the compressive strength of the cement as measured by the strength of a mortar composed of the cement and standard Ottawa sand. The ages at testing are 7 and 28 days.

2. This test is not included in the standard tests and specifications. It was proposed as a tentative standard in 1916 but has never been adopted. There is some feeling that as a strength test, a compression test would be better than the tension test.

Apparatus

Pan, beaker, trowel, and graduate
Balance
Six cylinder molds 2 × 4 in.
Twelve glass plates 2½ in. square
Water storage tank
Compression testing machine
Tamper

Specifications for Apparatus

3. *Molds.*—The molds may be made of any non-corroding metal. The ends must be parallel and the tubing shall be of sufficient thickness to prevent appreciable distortion.

4. *Tamper.*—The tamper shall be made of steel to the dimensions shown in Fig. 1.

Approximate weight ¾ lb.

FIG. 1.—Details of tamper.

5. *Testing Machine.*—Any testing machine may be used which meets the following requirement: The moving head of the testing machine shall travel at a rate of not less than 0.05 nor more than 0.10 in. per minute. The diameter of the spherical bearing block should be only a little greater than the diameter of the cylinder.

Material

Standard Ottawa sand meeting the requirements given for that material in tension-test specification.

Method

6. The procedure in this test runs parallel to that given in the tension test. Frequent reference will be made to the tension test.

7. *Preparation of Specimens.*—Prepare a standard mortar as given in the tension test. Either three 1,000-g. batches or one 3,000-g. batch may be prepared.

8. Clean and oil the molds. Place the mold on a smooth surface, preferably a piece of plate glass.

9. Mold the specimens immediately following the mixing. Place the mortar in the molds in layers approximately 1 in. thick. Tamp each layer with the steel tamper. Finish the test piece by heaping the mortar above the mold and smoothing off with a trowel. As soon as the cylinders from any batch are completed, cover with a piece of plate glass. Press the glass firmly against the fresh mortar.

10. *Care of the Specimen.*—At the end of 24 hours, remove the molds and place the cylinders in water in storage tanks. The water should be at a temperature of 21°C. (70°F.).

11. *Testing the Specimens.*—At 7 days remove the cylinders to be tested at 7 days and test immediately. The ends of the cylinders must be smooth, plane surfaces. The metal bearing plates of the testing machine must come in direct contact with the ends of the cylinder. Center the cylinder in the testing machine. Place the spherical bearing block on top of the cylinder. Determine the total load to crush the cylinder and then compute the load in pounds per square inch.

12. Repeat the test on the remaining cylinders at 28 days.

13. The reported result must be the average of at least three cylinders whose strength does not vary more than 15 per cent from the average of all cylinders tested at the same age.

Questions

1. Why does the compression test appear to be better than the tension test? Is there a constant relation between tension and compression results?
2. What effect would variations in temperature of the water in the storage tank have upon the test results?
3. What effect would a poor end condition have upon the test results?
4. What effect does the amount of tamping have upon the test results?
5. How many test pieces must be used in this test?

DATA RECORD—TEST NO. 7
COMPRESSION TESTS OF PORTLAND CEMENT

Material					O. P. C.	Lehigh
Date					1/15/30	2/14/30
Air temperature					27°C	°F
Weight of cement used					125 g	500 g
Weight of standard Ottawa sand used					375 g	1500 g
Weight of water used					53.5 cc	279 g
Number of cylinders molded					1	3
Size of cylinders					2"D	2"D x 4"L
Test results	Age	Specimen number	Total load, pounds	Unit load, pounds per square inch	Total load, pounds	Unit load, pounds per square inch
	7 days	1	6358	2100	7580	
		2	4314	1374	3535	
		3	5445	1800	4525	
		Average	5330	1690		
	28 days	1	4756	1510	4455	
		2	5900	1880	4750	
		3	6465	2060	11,000	
		Average	6700	2134		
Tentative specification requirements	7 days					
	28 days					

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TEST NO. 8

STANDARD METHOD OF TEST FOR DETERMINATION OF APPARENT SPECIFIC GRAVITY OF SAND, STONE, AND SLAG SCREENINGS, AND OTHER FINE NON-BITUMINOUS HIGHWAY MATERIALS

A. S. T. M. Serial Designation D55-25

Purpose

1. To determine the apparent specific gravity of sand, stone, and slag screenings, and other fine non-bituminous highway materials.

2. Le Chatelier and Jackson tests are equally suited and may be considered as alternates.

Le Chatelier Test

3. The procedure here is identical with that outlined for the determination of the specific gravity of Portland cement, except that the sample shall weigh between 50 and 64 g., depending upon the specific gravity of the material, and that either water or kerosene may be used as the liquid. A 55-g. sample will work for practically any material commonly used for fine aggregate.

4. The specification D55-25 does not call for dry sand in the Le Chatelier test but does in the Jackson test. For the Le Chatelier Test, however, the sample of sand should be dried to a constant weight at a temperature not to exceed 110°C., in the oven.

Jackson Test

Apparatus

Jackson specific gravity apparatus
Drying oven (to operate between 100 and 110°C.)
Balance (sensitive to 0.1 g.)
Thermometer (reading ordinary air temperatures)

Specifications for Apparatus

5. *Jackson Specific Gravity Apparatus.*—The Jackson specific gravity apparatus (illustrated in Fig. 1) shall consist of a burette, with graduations reading to 0.02 in specific gravity about 28 cm. (11 in.). in length and with an inside diameter of about 0.7 cm. (0.3 in.), which shall be connected with a glass bulb approximately 13 cm. (5⅛ in.) in length and 4.5 cm. (1.75 in.) in diameter, the glass bulb being of such size that from a mark on the neck above the bulb to the top graduation on the burette, the capacity shall be such that the graduations shall read directly the specific gravity when 50 g. of the materials are used; and an Erlenmeyer flask, which shall contain a hollow ground-glass stopper having a neck of approximately 6- to 8-mm. bore, and which shall have

a capacity of exactly 200 cc. up to the graduation on the neck of the stopper.

Method

6. *Preparation of the Sample.*—Weigh out 55 g. of material to be tested. Dry to a constant weight, at a temperature not exceeding 110°C. Weigh out 50 g. of the dry material to 0.1 g.

7. *Testing the Sample.*—Clean and dry the unstoppered Erlenmeyer flask. Pour the 50-g. sample into the flask.

8. Fill the bulb and burette with kerosene. Take the temperature of the kerosene by introducing a thermometer through the neck. Remove the thermometer and fill the bulb exactly to the mark on the neck.

9. Run into the flask about one-half the kerosene in the bulb, taking care to remove any air bubbles. Run more kerosene into the flask, removing any material adhering to the neck of the flask. At this point the kerosene should be just below the ground-glass neck.

10. Place the hollow ground-glass stopper into position and turn it to fit tightly. Run in kerosene exactly to the 200-cc. point, taking care to remove all air bubbles in the flask.

11. Read the specific gravity as indicated on the graduated burette. Take the temperature of the oil in the flask and determine the difference between this reading and the temperature previously taken of the oil in the bulb.

12. Make a temperature correction to the reading of the specific gravity in accordance with the table furnished by the manufacturer of the apparatus, adding the correction if the temperature of the kerosene has increased and subtracting it if the temperature of the kerosene has decreased.

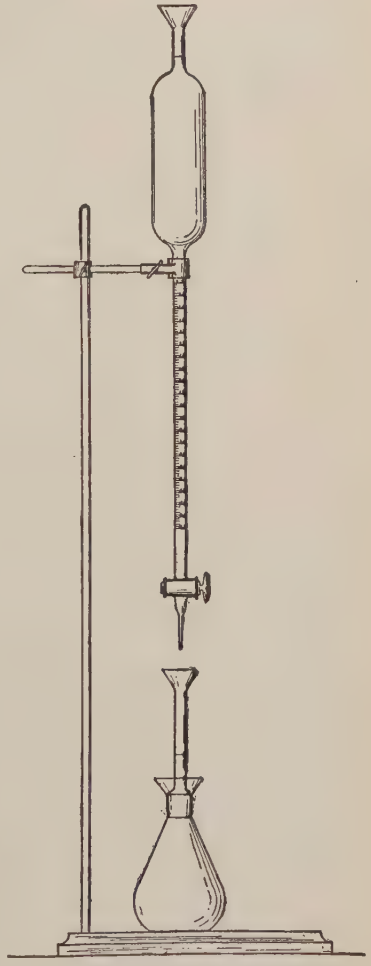


FIG. 1.—Jackson specific gravity apparatus.

Questions

Specific gravity questions follow test No. 9.

Data Record—Test No. 8

Determination of Apparent Specific Gravity of Sand, Stone, and Slag Screenings, and Other Fine Non-bituminous Highway Materials

Le Chatelier Test

Material	[illegible]	Sand
Date	10/[illegible]	2/21/30
Air temperature	27°C	72°F
Weight of material used	55 g.	55
Initial reading of flask	0.2	0.5
Final reading of flask	20.9	22.5
Volume of particles	20.7	22
Specific gravity	2.65	2.50

Jackson Test

Material		
Date		
Air temperature		
Weight of material used		
Temperature of oil in bulb		
Temperature of oil in flask		
Specific gravity as read on the burette		
Temperature correction		
Corrected specific gravity		

TEST NO. 9

DETERMINATION OF APPARENT SPECIFIC GRAVITY OF COARSE AGGREGATES

A. S. T. M. Serial Designation D30-18

Purpose

1. To determine the apparent specific gravity of coarse aggregates. Apparent specific gravity includes the voids in the specimen and is therefore always less than or equal to, but never greater than, the true specific gravity.

Apparatus

Balance (sensitive to 0.5 g.)
Drying oven (to operate between 100 and 110°C.)
Wire basket
½- or 1¼-in. screen

Specifications for Apparatus

2. *Wire Basket.*—The wire basket should be made of approximately ¼-in. mesh and be about 5 in. square and 4 in. deep.

Method

3. Weigh out 1,000 g. of coarse aggregate which is retained on a ½-in. screen. The pieces should be approximately cubical or spherical in shape. In the case of a homogeneous material, the smallest particles may be retained on a 1¼-in. screen.

4. Dry sample to a constant weight at a temperature between 100 and 110°C. Weigh to the nearest 0.5 g. Record this weight as A.

5. Immerse sample in water for 24 hours. Surface dry individual pieces with the aid of a towel or blotting paper. Weigh. Record this weight as B.

6. Suspend in water the wire basket from the center of a scale pan. Determine the weight of the basket immersed in water.

7. Place the sample of saturated coarse aggregate in the basket suspended in water. Weigh. Record the weight of the coarse aggregate immersed as C. (Do not include the weight of the basket immersed.)

$$\text{Apparent specific gravity} = \frac{A}{B - C}$$

Questions

1. Why is a specific gravity requirement rarely ever included in a set of specifications?

2. How does the specific gravity of a trap rock compare with the specific gravity of limestone?

3. An aggregate weighing 112.3 lb. per cubic foot has 32 per cent voids in it. What is the specific gravity?

4. Are there any voids in the particles themselves? How may this volume be determined?

DATA RECORD—TEST NO. 9

DETERMINATION OF APPARENT SPECIFIC GRAVITY OF COARSE AGGREGATE

Material	Pebbles	Pebbles
Date	[illegible]	2/25/30
Weight of material (A)	2000	2000 (1,608)
Weight of material (B)		
Weight of material and basket immersed	0	1629
Weight of basket immersed	1237	0
Weight of aggregate immersed (C)	1237	1629
Specific gravity	2.62	2.65

TEST NO. 10

TENTATIVE METHOD OF TEST FOR FIELD DETERMINATION OF APPROXIMATE SPECIFIC GRAVITY OF FINE AGGREGATE

A. S. T. M. Serial Designation C68-28T

Object

1. To determine the approximate apparent specific gravity of fine aggregate.

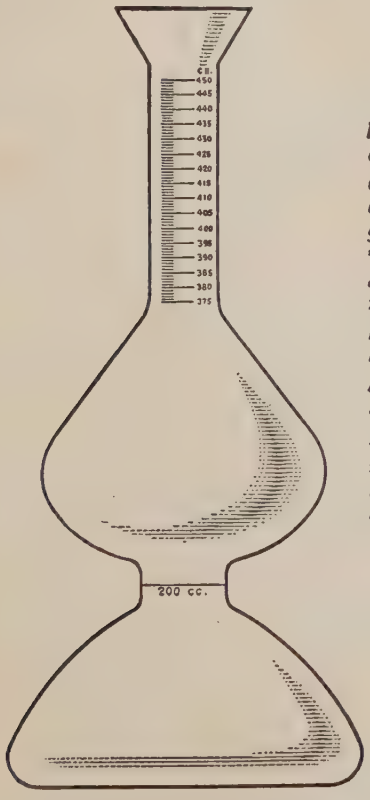
Apparatus

1 balance (2 kg. capacity, sensitiveness 0.5).

1 graduated flask for field testing of fine aggregate (Fig. 1). The range of use of this flask is from dry sand of 2.8 sp. gr. to sand of 2.2 sp. gr. having 10 per cent moisture.

Method

2. *Selection of Sample.*—Select a 1-kg. sample which shall be as representative as possible of the fine aggregate. Spread sample out on a flat surface and permit to air dry until the surface moisture has evaporated and the material is free flowing. Mix thoroughly and weigh out 500-g. sample.



Volume of lower chamber to mark on lower neck = 200 cc.

Combined volume of lower and upper chambers to lower end of graduated Scale on upper neck = 375 cc.

Scale graduated in 1cc. divisions from 375 cc. to 450 cc

Diameter of opening in lower neck, approximately $\frac{7}{8}$".

Diameter of bore of graduated upper neck, approximately $\frac{3}{4}$".

Diameter of base, approximately 4"

Diameter of funnel, approximately $1\frac{1}{2}$"

FIG. 1.—Flask.

3. *Testing.*—Fill the flask to the 200-cc. mark on the lower neck with water at room temperature. Pour into the flask slowly the 500-g. sample of fine aggregate agitating contents to free any entrained air. Read the combined volume in cubic centimeters on the scale on the upper neck of the flask.

4. *Computations.*—The approximate apparent specific gravity may be calculated from the formula:

$$\text{Approximate apparent specific} = \frac{500}{V - 200}$$

where V = the combined volume in cubic centimeters of the water and fine aggregate in the flask.

5. *Accuracy.*—Duplicate determinations should check to within 0.05. Variations in the amount of water evaporated from the moist sample as described in Sec. 2 beyond the point at which the surface moisture has disappeared and the sample is free flowing and apparently dry will cause variations in results of from 0.5 to 1 per cent depending upon the absorption of the aggregate.

DATA RECORD—TEST NO. 10

FIELD DETERMINATION OF APPROXIMATE SPECIFIC GRAVITY OF FINE AGGREGATE

Material	Sand-Fine	
Date	2/21/30	
Weight of sample, g.	500	
Initial reading flask, cc.	200	
Combined volume, cc.	390	
Volume aggregate, cc.	190	
Specific gravity	2.63	

TEST NO. 11

DETERMINATION OF UNIT WEIGHT OF AGGREGATE FOR CONCRETE

A. S. T. M. Serial Designation C29-27

Purpose

1. To determine the weight per unit bulk volume for a fine aggregate, a coarse aggregate, or a combination of the two. Weight per unit bulk volume should be distinguished from specific gravity.

Apparatus

Set of measures
Balance
Tamping rod
Shovel or small scoop

Specifications for Apparatus

2. *Set of Measures.*—The measure shall be of metal, preferably machined to accurate dimensions on the inside, cylindrical in form, water tight, and of sufficient rigidity to retain its form under rough usage, with top and bottom true and even, and preferably provided with handles.

3. The measures shall be of $\frac{1}{10}$-, $\frac{1}{2}$-, or 1-cu. ft. capacity, depending on the maximum diameter of the coarsest particles in the aggregate, and shall be of the following dimensions:

Capacity, cubic feet	Inside diameter, inches	Inside height, inches	Minimum thickness of metal, U. S. gage number	Diameter largest particles aggregate, inches
$\frac{1}{10}$	6.00	6.10	11	under $\frac{1}{2}$
$\frac{1}{2}$	10.00	11.00	8	under $1\frac{1}{2}$
1	14.00	11.23	5	over $1\frac{1}{2}$

4. The measure shall be calibrated by accurately determining the weight of water at 16.7°C. (62°F.) required to fill it. The factor for any unit shall be obtained by dividing the unit weight of water at 16.7°C. (62°F.) (62.355 lb. per cu. ft.) by the weight of water at 16.7°C. (62°F.) required to fill the measure.

5. *Balance.*—The balance should be sensitive to 0.5 per cent of the weight of the sample to be weighed.

6. *Tamping Rod.*—The tamping rod shall be a straight metal rod $\frac{5}{8}$ in. in diameter and 24 in. long, with one end tapered for a distance of 1 in. to a blunt bullet-shape point.

Method

7. For aggregate whose maximum diameter is ½ in. or less, use the $\frac{1}{10}$-cu. ft. measure.

8. For aggregate whose maximum diameter is over ½ in. and under 1½ in., use the ½-cu. ft. measure.

9. For aggregate whose maximum diameter is over 1½ in., use the 1-cu. ft. measure.

10. The sample of aggregate should be room dry and thoroughly mixed.

11. Fill the measure one-third full of aggregate. Level off with the fingers, tamp the aggregate with the pointed end of the tamper 25 times, evenly distributed over the surface. Do not forcibly strike the bottom with the tamper.

12. Fill now two-thirds full, level off, and tamp this layer in the manner prescribed for the first one-third. The rod should penetrate only the second layer.

13. Fill the measure full to overflowing. Tamp as for the second layer. Strike off the surplus with the tamping rod.

14. Determine the net weight of the aggregate in the container. Obtain the unit weight of the aggregate by multiplying the net weight of the aggregate by the factor found as described in Par. 4. Results with the same sample should check within 1 per cent.

15. *Specific Weight.*—It is frequently convenient to know the relationship between the weight of a material and the weight of an equivalent volume of water. When the volume is the solid volume of the particles, it is known as specific gravity. The relationship between the weight of a material and the weight of a volume of water equal to the bulk volume of a granular material might be termed the specific weight.

Questions

1. Why is it important that the amount of compaction be uniform from test to test?

2. Is the percentage of voids increasing or decreasing as the weight per unit volume increases and the specific gravity remains constant?

3. Will the weight per cubic foot of a sand with 6 per cent moisture in it be more or less than the weight per cubic foot of the same sand, dry? Why?

DATA RECORD—TEST NO. 11

DETERMINATION OF UNIT WEIGHT OF AGGREGATE FOR CONCRETE

Material	Sand	Sand *	Pea	Pea *
Date	10/8/28		10-8-28	
Size of container	1 ft.³	1 ft.³	1 ft.³	1 ft.³
Weight of material placed in container	50730 g	49490	47210	43[illegible]
Weight in pounds per cubic foot	[illegible]	103.0	[illegible]	96.[illegible]
Specific weight	1.79		1.64	
Weight in grams per cubic centimeter	1.79	1.74	1.69	1.54

* Unrodded

material — Sand

Date

Size of Container — $\frac{1}{10}$ cu ft — $\frac{1}{2}$ cu. ft.

Weight of material placed in container — 5078 g — 23,480 g.

Weight in lbs per cu ft — 112 — 103.5

Bulk Specific Gravity — 1.8 — 1.66

Weight in grams cu cm. — 1.8 — 1.66

TEST NO. 12

DETERMINATION OF THE EFFECT OF MOISTURE CONTENT AND INUNDATION UPON THE BULK VOLUME OF FINE AGGREGATE

Object

1. To determine of the effect of moisture content and inundation upon the bulk volume of fine aggregate, for any given gradation.

Apparatus

Balance (100-g. capacity)
500-cc. graduate
250-cc. graduate or burette
Small pan, beaker and trowel
Mixing pan

Method

2. Bulk volume of sand is quite variable. Factors affecting bulk volume are: amount of compaction, gradation, and moisture content. Gradation may be kept constant and the moisture content varied at will, but the item of compaction is not so simple. The percentages of bulking depend to some extent upon the amount of compaction given the dry sand. Sand poured loosely into a container has the greatest volume and the volume decreases as the count of compacting effort increases. Since most specifications now call for fine aggregate to be measured on the basis of loose and dry condition, it is suggested that the percentage of bulking be computed on the basis of loose dry sand.

3. *Determination of Quantities.*—Place sand in the 500-cc. graduate until filled to the 300-cc. mark. Pour into small pan and weigh. For each succeeding batch weigh out the same amount of sand as just determined.

4. *Inundation.*—One of the methods now in use in the measurement of fine aggregate is to measure it under water. Pour into the 500-cc. graduate approximately 100 cc. of water. Introduce the sand now slowly. The level of water should always be above the sand. If the original amount of water is not sufficient, add more. Read the volume of the sand. This is known as the inundated volume. Compare it with the volume of the loose dry sand.

5. *Bulking Tests.*—Weigh out the amount of aggregate as determined in Sec. 3. Mix this with 2 per cent of its weight of water. The mixing should be done in the mixing pan with a trowel. As soon as the mixing is complete, place the sand in the 500-cc. graduate and note its volume. This is known as the bulked volume for 2 per cent of moisture.

Remove moist sand from graduate and determine inundated volume as described in Sec. 4.

Make bulked and inundated volume determinations for other percentages of moisture. Other percentages suggested are 4, 6, 8, 10, and 15.

6. *Curves.*—On a sheet of 20-in. coordinate paper plot bulked and inundated volumes against moisture content.

Questions

1. Which moisture content gives maximum bulking? How much bulking?

2. How do the inundated volumes compare with the dry volume? What factors may affect these values?

3. Are the inundated volumes uniform regardless of the amount of moisture in the sand?

4. Is inundation a satisfactory way of securing uniform amounts of fine aggregate from batch to batch?

DATA RECORD—TEST NO. 12

DETERMINATION OF EFFECT OF MOISTURE CONTENT AND INUNDATION UPON BULK VOLUME OF FINE AGGREGATE

Material _____

Dry sand used: Volume _____ Weight _____

Moisture		Bulked volumes		Inundated volumes	
Percentage	Weight, grams	Volume, cubic centimeters	Percentage[1]	Volume, cubic centimeters	Percentage[1]
			63		-5
					-3
					-3

[1] Increase or decrease based on dry volume.

TEST NO. 13

STANDARD METHOD OF TEST FOR

DETERMINATION OF VOIDS IN FINE AGGREGATE FOR CONCRETE

A. S. T. M. Serial Designation C30-22

Purpose

1. To determine the percentage of voids in a fine aggregate.

Apparatus

2. No apparatus is necessary. Determinations of the specific gravity and the weight per unit bulk volume, however, must be made first.

Method

3. The voids in the fine aggregate for cement concrete are determined by the formula:

$$\text{Percentage of voids} = \frac{(\text{specific gravity} \times 62.355) - \text{weight}}{\text{specific gravity} \times 62.355} \times 100$$

in which "specific gravity" represents the apparent specific gravity of the fine aggregate as determined by the test for apparent specific gravity, D55-25, and "weight" represents the weight in pounds per cubic foot of the fine aggregate as determined by the test for unit weight of aggregate for concrete, C29-21. The quantity 62.355 is the weight in pounds of 1 cu. ft. of water at the standard temperature of 16.7° C. (62°F.).

4. When the weight per unit volume is in the metric system, the percentage of voids is figured in the following manner:

$$\text{Percentage of voids} = \frac{\text{specific gravity} - \text{weight per unit volume}}{\text{specific gravity}}$$

NOTE.—This procedure is equally applicable to coarse aggregates as well as fine aggregates.

Questions

1. What factors affect the percentage of voids in a material?
2. Why is it desirable to have the voids in an aggregate at a minimum?
3. Mix 1,000 g. of a sand of a specific gravity of 2.65 with 2,000 g. of crushed trap rock of a specific gravity of 2.85. The mixture has a volume of 1,500 cc. What is the percentage of voids?

DATA RECORD—TEST NO. 13

DETERMINATION OF VOIDS IN FINE AGGREGATE FOR CONCRETE

Material	Cem. 1	Sand	Brick S
Date	2/28/30	2/28/30	
Specific gravity			
62.355 × specific gravity			
Weight per cubic foot			
Difference			
Percentage of voids			

TEST NO. 14

TENTATIVE METHOD OF TEST FOR FIELD DETERMINATION OF APPROXIMATE PERCENTAGE OF VOIDS IN FINE AGGREGATE

A. S. T. M. Serial Designation C69-28T

Object

1. To determine the approximate percentage of voids in fine aggregate when inundated with water.

Apparatus

1 balance (2-kg. capacity and sensitive to 0.5 g.)

1 graduated flask for field testing of fine aggregate (see Fig. 1, Test No. 10)

Method

2. *Selection of Sample.*—Select a 2-kg. sample which shall be as representative as possible of the fine aggregate. Spread sample out on a flat surface and permit to air dry until the surface moisture has evaporated and the material is free flowing.

3. *Testing.*—Weigh the flask. Place about 100 cc. of water in the flask. Do not agitate the aggregate in the flask during or after the filling operation. Introduce slowly aggregate from the room-dry sample until the flask is filled to the 400-cc. mark. Add water as required to keep the aggregate inundated as the filling proceeds. When the flask is filled to the 400-cc. mark, both the water and aggregate should be at the same level. Determine weight of the contents of the flask to the nearest gram.

4. *Computations.*—The approximate percentage of voids in the inundated fine aggregate may be calculated from the formula:

$$V = \frac{400 \times \text{specific gravity} - W}{400(\text{specific gravity} - 1)} \times 100$$

in which

V = the approximate percentage of voids.

Specific gravity = apparent specific gravity of the fine aggregate.

W = combined weight in grams of 400 cc. of water and fine aggregate in the flask.

If the approximate apparent specific gravity is not known determine as outlined in Test No. 10.

5. *Accuracy.*—Duplicate determinations should check within 1 per cent. Variations in the composition of the rock grains of the fine aggregate which result in variations in 0.5 in the approximate apparent specific gravity of the aggregate will cause an inaccuracy in results equal to from 2 to 3 per cent of voids.

DATA RECORD—TEST NO. 14

FIELD DETERMINATION OF APPROXIMATE PERCENTAGE OF VOIDS IN FINE AGGREGATE

Material		Sand
Date		2/21/30
Specific gravity[1]		2.63
Weight of flask, g.		187.
Weight of flask and contents, g.		1030
Combined volume of contents, cc.		400.
Percentage of voids		21.0

[1] Determined in Test No. 10.

TEST NO. 15

TENTATIVE METHOD OF TEST FOR FIELD DETERMINATION OF SURFACE MOISTURE IN FINE AGGREGATE

A. S. T. M. Serial Designation C70-28T

Object

1. To determine approximately the percentage of surface moisture in fine aggregate for use in computing the allowance to be made for water in the fine aggregate when proportioning concrete by the maximum water content method. Surface moisture is defined as that moisture which is on the outside of the particles. The moisture within the particles does not add to the volume of the particles and therefore does not make itself evident in this test.

Apparatus

1 balance (capacity 2 kg., sensitiveness 0.5. Preferably of torsion type)

1 graduated flasks for field testing of fine aggregate (see Fig. 1 of test No. 10)

Method

2. *Selection of Sample.*—Select a 1-kg. sample which shall be as representative as possible of the fine aggregate. Mix thoroughly and spread out on a flat non-absorbent surface. Weigh out immediately 500 g., permitting moisture to evaporate as little as possible from the sample.

3. *Testing.*—Fill the graduated flask to the 200-cc. mark on the lower neck with water at room temperature. Pour slowly into the flask now the 500-g. sample. Agitate or stir the contents of the flask to free any entrained air bubbles. Read the combined volume of the water and fine aggregate on the scale on the upper neck of the flask.

4. *Computations.*—The percentage of surface moisture in the fine aggregate based on surface dry aggregate may be calculated from the formula:

$$\text{Percentage of surface moisture} = \frac{V - \frac{500}{\text{specific gravity}} - 200}{200 + 500 - V} \times 100$$

in which

V = the combined volume in cubic centimeters of the water and fine aggregate in the flask.

Specific gravity = approximate apparent specific gravity of the fine aggregate which is determined in accordance with the procedure outlined in Test No. 10.

5. *Accuracy.*—Duplicate determinations should check to within 0.5 per cent. Variations in the composition of the rock grains of the fine aggregate which result in variations of 0.05 in the approximate apparent specific gravity of the aggregate will cause inaccuracy in results equal to from 1 to 1.5 per cent of moisture.

DATA RECORD—TEST NO. 15

FIELD DETERMINATION OF SURFACE MOISTURE IN FINE AGGREGATE

Material	Sand	Sand
Date	1/29/30	2/1/30
Weight of sample, g.	500 g	500 g
Initial reading of flask, cc.	200	200
Final reading of flask, cc.	393	398
Specific gravity[1]	2.65	2.63
Percentage of surface moisture		.98

[1] Determined in Test No. 10.

TEST NO. 17

DETERMINATION OF SIEVE ANALYSIS OF AGGREGATES FOR CONCRETE

A. S. T. M. Serial Designation C41-27

Purpose

1. To determine the relative amounts of the various sized particles present in an aggregate.

Apparatus

Balance
Nest of sieves, pan, and cover
Sieve shaker for fine aggregate
Drying oven (to operate between 100 and 110°C.)

Specifications for Apparatus

2. *Sieves.*—The sieves shall be of square-mesh wire cloth and shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sifting. The size of wire and sieve openings shall be as given in Table 1.

3. *Balance.*—The balance shall be sensitive to one-thousandth of the weight of the test sample.

TABLE 1.—SIEVE REQUIREMENTS AS GIVEN IN TABLE 1, A. S. T. M. STANDARD
Serial Designation C41-27

Sieve number[1] or size in inches	Sieve opening		Wire diameter		Tolerance, per cent			
	Millimeters	Inches	Millimeters	Inches	Average opening	Wire diameter		Maximum opening
						Under	Over	
No. 100	0.149	0.0059	0.102	0.0040	6	15	35	40
No. 50	0.297	0.0117	0.188	0.0074	6	15	35	40
No. 30	0.59	0.0232	0.33	0.0130	5	15	30	25
No. 16	1.19	0.0469	0.54	0.0213	3	15	30	10
No. 8	2.38	0.0937	0.84	0.0331	3	15	30	10
No. 4	4.76	0.187	1.27	0.050	3	15	30	10
⅜ in.	9.5	0.375	2.33	0.092	3	10	10	10
¾ in.	19.0	0.75	3.42	0.135	3	10	10	10
1 in.	25.4	1.00	4.12	0.162	3	10	10	10
1½ in.	38.0	1.50	4.50	0.177	3	10	10	10
2 in.	50.8	2.00	4.88	0.192	3	10	10	10
3 in.	76.0	3.00	6.3	0.25	3	10	10	10

[1] The requirements for sieves No. 100 to No. 4 conform to the requirements of the U. S. Standard Sieve Series as given U. S. Bureau of Standards *Letter Circular* 74. The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the numbers given in the table.

Method

4. The sieves to be used will depend upon the purpose of the analysis. If the purpose of the analysis is to check an aggregate against a specification, then the sieves named in the specification should be used. If it is desired to compute Abrams' fineness modulus, then the following sieves of the Tyler standard series should be used: Nos. 100, 48, 28, 14, 8, 4, ⅜ in., ¾ in., and 1½ in. The No. 3 or ¼-in. sieve should always be used, as it is the dividing line between fine and coarse aggregate.

FIG. 1.—A type of mechanical sieve shaker. An automatic cutout switch is located in the box just above the shaker.

5. Some specifications specify screens for the coarse aggregate instead of sieves. This item should be watched carefully as the results will be quite different for the same material. The difference will be greater using a crushed stone than with pebbles.

6. *Preparation of Sample.*—Select a representative test sample of the aggregate by quartering or by use of a sample splitter, which after drying will have not less than the following:

7. Fine aggregate 500 g.

8. Coarse aggregate or a mixture of fine and coarse aggregates, weight in grams, 3,000 times the size of the largest sieve required, measured in inches.

9. Dry the sample to a constant weight at a temperature not over 110°C.

Fine Aggregate

10. *Testing the Sample.*—Weigh out 500 g. of the fine aggregate.

11. Arrange the sieves in order, with the sieve having the largest diameter of opening at the top and with a pan on the bottom. Place the sample on the top sieve. Cover.

12. Place the nest of sieves in a sieve shaker and shake until not more than 1 per cent by weight of the sample passes any of the sieves in 1 min. of continuous shaking. It is common practice to shake the sample 15 min. If the shaking is done by hand, use the sieves individually and begin with the one having the largest openings. Follow in general the procedure outlined in the test for fineness of cement. The material shaken on the second sieve should be only that passing the first sieve used.

13. Weigh each time all the material that is coarser or finer than each sieve. When machine shaking is used, it is more convenient to weigh the amounts coarser. With hand shaking one is as convenient as the other. Compute percentages passing or retained, as desired.

Coarse Aggregate

14. *Testing the Sample.*—With coarse aggregate it is not possible to use machine shaking. Separate the entire sample on the sieve with the largest openings. Weigh the amount retained. On the sieve with the next smaller openings, separate the part of the sample which passed through the first sieve. Add the part retained on the second sieve to the part retained on the first sieve and weigh. This gives the total amount of the material which is larger or coarser than the second sieve.

15. Repeat with other sieves in order.

16. Compute the percentages passing or retained, as desired, based on the total weight of the dry sample.

17. *Report.*—The percentages in the sieve analysis shall be reported to the nearest whole number.

18. If more than 15 per cent of a fine aggregate is coarser than the No. 4 sieve, or more than 15 per cent of a coarse aggregate is finer than the No. 4 sieve, the sieve analysis of the portions finer and coarser than this sieve shall be reported separately.

Questions

1. How is it possible to secure results for certain sieves which may not be used in the performance of the test?

2. How is it possible to secure results in terms of the portions passing one sieve and retained on another, when the sieve analysis is made giving results in terms of the entire batch split on each sieve?

3. Why is grading of the aggregate important?

Data Record—Test No. 17

Determination of Sieve Analysis of Aggregates for Concrete

Material	Sand							Pebbles					
Date	2/28/30							1/4/28					
Shaker used	Ro-Tap							Hand					
Time of shaking	15 min.												
Weight of sample	500 g.							5,000 g					
Sieve number	Diameter opening	Weight retained	Per cent retained	Per cent passing	Weight retained	Per cent retained	Per cent passing	Weight retained	Per cent retained	Per cent passing	Weight retained	Per cent retained	Per cent passing
4	.185	10	2			1½	1.48"	0	0	100			
8	.093	55	11			"	1.05	2145	43	57			
14	.046	150	30			¾"	.742	3310	66	34			
20	.0328	220	44			½"	.525	3680	73.5	26.5			
28	.0232	290	58			⅜	.371	4315	86.9	13.6			
48	.0116	435	87			¼	.263	4505	90.0	10			
100	.0058	490	98										

Passes #1 dries [illegible] Does Not Pass #1 Pan

TEST NO. 18

DECANTATION TEST FOR SAND AND OTHER FINE AGGREGATES

A. S. T. M. Serial Designation D136-22T

Purpose

1. To determine the total quantity of silt, loam, clay, etc., in sand or other fine aggregates. This determination will include all water-soluble material present, the percentage of which may be determined separately if desired.

Apparatus

Drying oven (to operate between 100 and 110°C.)
Balance
Pan
Timepiece indicating seconds

Specifications for Apparatus

2. *Pan.*[1]—The pan or vessel to be used in the determination shall be approximately 9 in. (230 mm.) in diameter and not less than 4 in. (102 mm.) deep.

Method

3. *Preparation of the Sample.*—Thoroughly mix the sample, which shall contain sufficient moisture to prevent segregation. Select (by quartering or sample splitter) a representative sample sufficient to yield approximately 500 g. of dried material. Dry to a constant weight in an oven at a temperature not to exceed 110°C. Weigh.

4. *Testing the Sample.*—Place the dried sample in the pan with sufficient water to cover the sample (about 225 cc.). Agitate the contents of pan vigorously for 15 sec. and then allow to settle for 15 sec. Pour off the water, being careful not to pour off any sand. Repeat this operation until the wash water is clear. As a precaution, pour the wash water through a 200-mesh sieve and return to the sample any material retained thereon.

5. Dry the washed sand to a constant weight at a temperature not exceeding 110°C. Weigh.

6. Check results may be obtained by saving the wash water, evaporating to dryness, and weighing the residue. This is rarely done, however.

7. *Result.*—The percentage of silt, loam, clay, etc. is based on the original dry weight of the sample.

[1] The exact shape of the pan seems immaterial, but is specified in the A. S. T. M. standard.

Questions

1. What limits are usually placed for this test requirement?
2. What effect does silt in the aggregate have upon the compressive strength of concrete?
3. Why is silt particularly objectionable in aggregates to be used in portland cement concrete pavements?

DATA RECORD—TEST NO. 18

DECANTATION TEST FOR SAND AND OTHER FINE AGGREGATE

Material	Sand	
Date		
Weight of material		
Weight of material after washing and drying		
Weight of silt		
Percentage of silt		

TEST NO. 19

DETERMINATION OF PRESENCE OF ORGANIC IMPURITIES IN SAND FOR CONCRETE

A. S. T. M. Serial Designation C40-27

Purpose

1. To determine the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests are necessary before the sand be used in concrete.

Apparatus

Two 12-oz. clear glass graduated bottles (only one necessary when color chart is available)

Chemicals

50 cc. of 3 per cent solution of sodium hydroxide (NaOH) in water
2.5 cc. of 2 per cent solution of tannic acid in 10 per cent alcohol (not necessary when color chart is available)

Method

2. Select a representative sample of 1 lb. by quartering or by use of a sample splitter. Fill one 12-oz. bottle to the 4½ oz. mark with sand. Add 3 per cent solution of sodium hydroxide until the volume of the sand and solution amounts to 7 oz. Shake thoroughly. Allow to stand 24 hours. Compare color of clear liquid above the sand with the standard color solution, or with the color chart.

3. *Preparation of a Standard Color Solution.*—When a color chart is not available, a standard color solution may be made as follows: Add 2.5 cc. of a 2 per cent solution of tannic acid in 10 per cent alcohol, to 97.5 cc. of a 3 per cent solution of sodium hydroxide in water. Place the solution in the other 12-oz. bottle, stopper, and allow to stand for 24 hours.

4. Color charts or colored glasses are available and may be used in place of the solution. Solutions darker in color than the standard color have a "color value" higher than 250 parts per million in terms of tannic acid.

Questions

1. What is the purpose of this test?
2. What should be done with an aggregate which shows a color darker than the standard color?

DATA RECORD—TEST NO. 19

DETERMINATION OF PRESENCE OF ORGANIC IMPURITIES IN SAND FOR CONCRETE

Material	1	
Date	2/28/30	
Time sand is immersed in sodium hydroxide solution	24	
Comparison with standard color at the end of 24 hours	No. 3.	

TEST NO. 20

DETERMINATION OF SOUNDNESS OF COARSE AGGREGATE

As given in "Tentative Standard Methods of Sampling and Testing Highway Materials," U. S. Department of Agriculture Bulletin 1216, *p.* 8. *There is no A. S. T. M. standard.*

Purpose

1. To determine the soundness of a coarse aggregate. Some aggregates show satisfactorily in other tests but disintegrate when subjected to freezing and thawing. This test has been devised for use where it is not possible to subject the material to actual freezing and thawing.

Apparatus

1,000-cc. beaker
Drying oven (100°C.)
Balance (1,500-g. capacity)

Chemicals

500 cc. saturated (at 70°F.) sodium sulfate solution (Na_2SO_4)

Method

2. Select 10 pieces of aggregate whose total weight is approximately 1,000 g.

3. Immerse the sample of rock in the saturated sodium sulfate solution for 20 hours. Remove the sample and place in a drying oven for 4 hours. The temperature of the drying oven should be 100°C.

4. Repeat five times. Examine pieces at the end of the test for evidence of unsoundness. Samples which show marked checking, cracking, or disintegration fail to pass this test.

Questions

1. What is the practical value of this test?

2. What is likely to happen to the concrete if an unsound aggregate should be used in it?

DATA RECORD—TEST NO. 20

DETERMINATION OF SOUNDNESS OF COARSE AGGREGATE

Material	Rock	
Date	9/22/28	
Weight of sample used	1000 g	
Number of pieces	15	
Condition of sample at end of test period	Unsound	

TEST NO. 21

TENSION TEST FOR FINE AGGREGATE

The following test is outlined by the writer and follows very closely the procedure given for the tension test of cement. There is no A. S. T. M. standard for tension test for fine aggregate. Tensile strength requirements are frequently given in specifications with the expectation that the procedure for making test specimens as given in the A. S. T. M. tension test will be followed.

Purpose

1. To determine the mortar- and concrete-making qualities of a fine aggregate, as measured by the tensile strength of briquets made using that fine aggregate and compared with the tensile strength of briquets made using the same cement and standard Ottawa sand, in the same proportions and of the same consistency.

Apparatus

Pan, beaker, trowel, and graduate
Balance
Four 3-gang briquet molds
Five glass plates, approximately 3 × 12 in.
Water storage tank
Moist closet
Briquet testing machine

Specifications for Apparatus

2. This apparatus is the same as that specified in the tension test of cement.

Method

3. In this test it is necessary to make two batches of mortar, one using the sand being tested and any brand of portland cement and the other using standard Ottawa sand and the same cement used in the first batch. The ratio of cement to sand is 1:3 by weight. In student work it is convenient to make the tension tests of cement and sand at the same time. Thus the tension test of cement will serve a double purpose. In case both tests are made at the same time, the student should note that the briquets made with standard Ottawa sand are the tension test of cement and a part of the tension test of sand.

4. *Preparation of the Specimens.*—The preparation of the specimens using standard Ottawa sand is exactly as described in the tension test for cement. The mortar in the specimens using the sand being tested should be of the same consistency as the standard Ottawa sand mortar. The tester must use his own judgment in making the two mortars of the

same consistency. The standard Ottawa sand mortar should be made first.

5. *Care of the Specimens.*—Same as in tension test for cement.

6. *Testing the Specimens.*—Same as in tension test for cement. Three of a kind are tested at 7 and at 28 days.

DATA RECORD—TEST NO. 21

TENSION TESTS OF SAND FOR CONCRETE

Material			U.P. Sand			
Date			9/22/28		2	
Air temperature					75° F	
Brand of cement used			Universal		High	
Weight of cement used			250 g			
Weight of sand used			750 g			
Weight of water used with S. O. S. mortar			107 g		10	
Weight of water used with test sand mortar			125		110	
Test results	Age	Specimen number	S. O. S.	Test sand	S. O. S.	Test sand
	7 days	1		165		
		2		175		
		3		170		
		Average		170		
	28 days	1	295	410		
		2				
		3				
		Average				

TEST NO. 22

COMPRESSION TEST FOR FINE AGGREGATE

The following test is outlined by the writer and follows very closely the procedure given for the compression test of cement, which is a tentative A. S. T. M. standard. There is no A. S. T. M. standard for compression test for fine aggregate. Compressive strength requirements are frequently given in specifications without any outline of a definite method for the performance of the test.

Purpose

1. To determine the mortar- and concrete-making qualities of a fine aggregate, as measured by the compressive strength of cylinders made using that fine aggregate and compared with the compressive strength of cylinders made using the same cement and standard Ottawa sand, in the same proportions and of the same consistency.

Apparatus

Pan, beaker, trowel, and graduate
Balance
Twelve cylinder molds 2 × 4 in.
Twenty-four glass plates 2½ in. square
Water storage tank
Tamper
Compression testing machine

Specifications for Apparatus

This apparatus is the same as that specified in the compression test for cement.

Method

2. In this test it is necessary to make two kinds of mortar, one using the sand being tested and any brand of portland cement, and one batch using standard Ottawa sand and the same cement used in the first batch. The ratio of cement to sand is 1:3 by weight. In student work it is convenient to make the compression tests of cement and sand at the same time. Thus the compression test of cement will serve a double purpose. In case both tests are made at the same time, the student should note that the cylinders made with standard Ottawa sand are the compression test of cement and a part of the compression test of sand.

3. *Preparation of Specimens.*—The preparation of the specimens using standard Ottawa sand is exactly as described in the compression test for cement. The mortar in the specimens using the sand being tested should be of the same consistency as the standard Ottawa sand mortar. The tester must use his own judgment in making the two mortars of the same consistency. The standard Ottawa sand mortar should be made first.

4. *Care of Specimens.*—Same as in the compression test for cement.

5. *Testing Specimens.*—Same as in the compression test for cement. Three of a kind are tested at 7 and at 28 days.

TENSION AND COMPRESSION TESTS OF FINE AGGREGATE

Questions

1. Why is it necessary in these tests to use the same brand of cement for both batches of mortar?
2. Write the usual specification for these requirements for a sand to be used in pavement construction.
3. Would variations in the temperature of the water in the storage tank affect the test results?

DATA RECORD—TEST NO. 22
COMPRESSION TEST FOR FINE AGGREGATE FOR CONCRETE

Material			Sand			
Date			2/14/13			
Air temperature			75°F			
Brand of cement used			Lehigh			
Weight of cement used						
Weight of sand used			7518			
Weight of water used with S. O. S. mortar			1079.			
Weight of water used with test sand mortar			1109			
	Age	Specimen number	Standard Ottawa sand mortar		Test sand mortar	
			Total load, pounds	Unit load, pounds per square inch	Total load, pounds	Unit, pounds per square inch
Test results	7 days	1			3980	
		2			5460	
		3			7460	
		Average				
	28 days	1			12750	
		2			11200	
		3			11530	
		Average				

TEST NO. 25

MORTAR VOIDS TEST

Object

1. To secure data to plat the mortar-voids curves for use in connection with Professor Talbot's method of proportioning concrete.

Apparatus

Balance (1,000-g. capacity)
Container (200- to 250-cc. capacity)
Steel tamper (see Fig. 1 of Test No. 7)
2 mixing pans

Method

2. The purpose of these tests is to secure data concerning the composition of mortars composed of any cement and any sand. For the same amounts of water the composition of mortars varies as the cement or sand is changed. It is not possible to make the determination using any materials and expect these values to hold for all other similar materials.

In making the series of mortar-voids tests for a given sand, Professor Talbot used the following ratios of sand to cement, all by solid or absolute volumes: 0, 1, 2, 3.5, and 5. This range covers all the values ever used in concrete. The 0-ratio is neat cement, which is rarely used. The 5-ratio is also rarely used. For each ratio of sand to cement, the water content is determined which will produce a minimum of voids. The water content which produces minimum voids is known as basic water content. After basic water content is determined, batches are mixed with water contents 20 to 40 per cent in excess of basic water content so that the composition of these mortars may be noted.

3. *Determination of Quantities of Materials.*—Not knowing the materials, it is difficult to give a definite procedure. Professor Talbot in the original studies used enough material so that the solid volume of the cement and the sand was equal to the volume of the container. The addition of the water increased the volume of the mortar so that it was not possible to get all of the mortar into the container.

Determination of the quantity of mixing water to produce minimum voids is a *cut-and-try* process. Use an amount of water first which it is thought will be somewhere near the correct amount. Base other amounts upon the first and succeeding determinations.

4. *Mixing.*—Weigh out materials for one batch. Mix sand and cement dry. Add water and proceed with mixing as outlined in Test No. 6. Begin the filling of the container as soon as the mixing is completed.

5. *Testing.*—Fill the container in 4 increments, tamping each increment 10 strokes with the tamper. Care should be exercised to make the strokes uniform. Smooth off the surface with a trowel. Determine the weight of the amount of mortar placed in the container.

6. Mix and test other batches until the amount of mixing water which will produce minimum voids is determined. Repeat with 20 and 40 per cent more water.

7. Repeat for other ratios of sand to cement until the entire range is covered as suggested in Sec. 2.

8. *Computations.*—Assuming that the portion of the batch which is placed in the container is representative of the entire batch, compute the volume of the batch from the following equation:

$$\frac{\text{Volume of batch}}{\text{Volume of container}} = \frac{\text{weight of batch}}{\text{weight of portion placed in container}}$$

For each batch compute the following:

1. Volume of batch.

2. Solid volumes of cement and sand (found by dividing the weight of each used by its specific gravity).

3. Proportions of water, cement and sand (found by dividing the absolute or solid volume by the volume of the batch).

4. Proportion of voids (found by subtracting from 1 the values for cement and sand determined in the preceding item).

5. Cement-space ratio (found by dividing the value for solid volume of cement by the sum of the values for cement and voids).

9. *Curves.*—Plat characteristic curves similar to those shown in Fig. 51.

TEST NO. 31

EFFECT OF THE AMOUNT OF MIXING WATER ON COMPRESSIVE STRENGTH OF CONCRETE FOR A GIVEN MIX

Object

1. To show the effect of the amount of mixing water on the compressive strength of concrete, keeping the proportions of cement and aggregate the same.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates (at least three molds and six plates for each batch of concrete)
Standard tamping rod
Slump cone (and flow table)
Compression testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. There are two general types of problems which may be performed under the general heading *The Effect of the Amount of Mixing Water on the Compressive Strength of the Concrete.* In the first case the proportions of the cement and aggregates may be kept constant and the amount of mixing water varied. This will produce concrete of different consistencies. In the other case the ratio of water to cement may be varied and the consistency kept approximately constant by varying the proportions of cement and aggregates. In both cases the water-cement ratio is varied, but in the one the consistency is varied while in the other it is kept constant. In this problem the proportions of cement and aggregates are kept constant and the consistency varied.

3. *Proportions.*—Any proportions of cement to aggregate may be used. The selection of the exact proportions will depend somewhat upon the materials and the purpose of the tests. The author has found a 1:2¼:4 or a 1:2½:4 mix convenient and giving a satisfactory range of values. Maximum strength will be secured for these proportions with a water-cement ratio of approximately 0.9. A water-cement ratio of 0.6 or 0.7 will produce dry and unworkable concrete, and a water-cement ratio of 1.4 will produce concrete which is too wet to be classed as workable. If time and equipment permit it is suggested that the water-cement ratio be varied from 0.7 to 1.4 by 0.1 interval. For other proportions the range will be slightly different.

4. *Determination of Quantities.*—Determine the quantities of materials necessary to make enough concrete to fill the molds and allow about 10 per cent excess for loss in handling. See chapter on *Estimating Quantities of Materials for Concrete.* Determine the weight of each material to be used in each batch. Weigh out the materials for the batches as required.

5. *Mixing.*—Put all the materials, including the water, into the mixer and mix either 1, 1½, or 2 min. Mix all batches the same length of time, however. Dump the entire batch into the large pan or wheelbarrow. If concrete does not come out of the mixer uniformly, stir in the pan or wheelbarrow until uniform.

6. *Consistency Tests.*—Make either or both the slump and flow tests for consistency.

7. *Slump Test.*[1]—Place slump cone on a flat, non-absorbent surface. Hold the form firmly in place while it is being filled by standing on the foot pieces. Fill the mold with concrete to about one-fourth its height. Puddle with a ⅝-in. rod, 24 in. in length and bullet pointed at the lower end. Fill the mold in successive layers and puddle as in the case of the first layer. Strike off the concrete so that the mold is exactly full. Immediately after filling remove the mold by raising it vertically. Allow the molded concrete to subside until quiescent and measure the height of the specimen. *The slump value is equal to the original height minus the final height and is given in inches.*

8. *Flow Test.*[2]—Place the metal mold in the shape of a frustum of a cone 6¾ in. in top diameter, 10 in. in bottom diameter, 5 in. in depth, on the table of the flow apparatus. Place the fresh concrete in the mold in 2 layers and puddle each layer as prescribed above under slump test. Strike off the surplus concrete with a trowel and remove the mold with a steady upward pull. Raise the table ½ in. and drop fifteen times in about 10 sec. Measure the average diameter of the concrete. *The flow is the spread of the concrete due to this treatment expressed as a percentage of the original bottom diameter of the cone.*

9. *Molding Cylinders.*—After the consistency tests have been made, mold the desired number of cylinders, in the following manner:[3]

Place concrete in the molds in layers 3 to 4 in. in thickness. Puddle each layer with 25 strokes of a ⅝-in. rod 24 in. in length and bullet pointed at one end. After the top layer has been puddled strike off

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[1] As outlined in "Tentative Method of Test for Consistency of Portland-cement Concrete," *A. S. T. M. Serial Designation* D138-26T.

[2] As outlined in "Standard Methods of Making Compression Tests of Concrete," *A. S. T. M. Serial Designation* C39-27.

[3] This is the method prescribed in "Standard Methods of Making Compression Tests of Concrete," *A. S. T. M. Serial Designation* C39-27. See pages 227–232.

surplus with a trowel and cover with a piece of plate glass ¼-in. in thickness or with a machined plate.

10. *Capping Cylinders.*—After an interval of from 2 to 4 hours, cap the cylinders in the following manner: Mix up a batch of neat cement paste to a fairly stiff consistency at the time the cylinders are made. Apply a thin layer of the cement paste over the end of the cylinder.

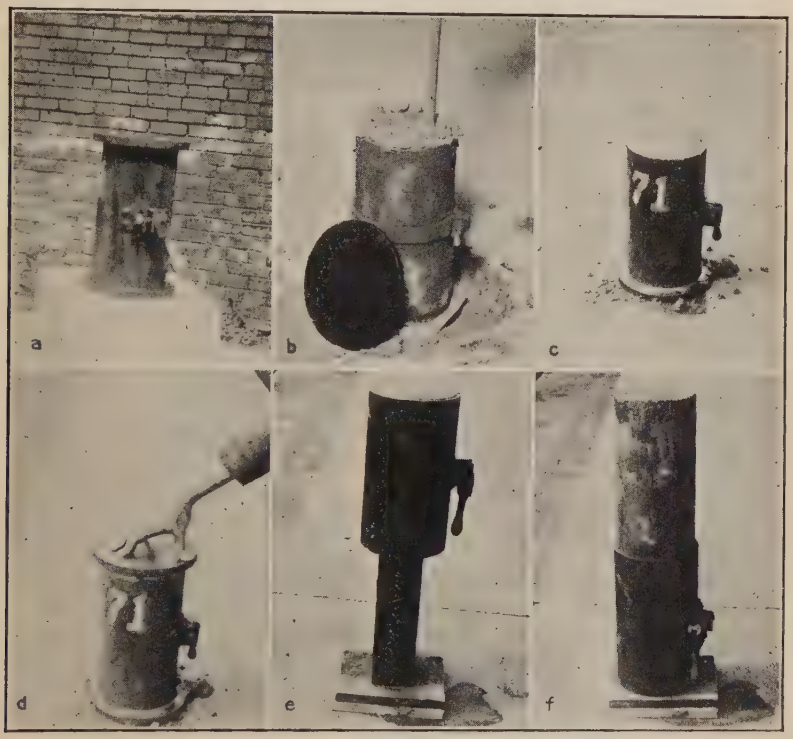


FIG. 1.—Preparation of cylinders.

a, The mold. Note the device for opening and closing. Plates for top and bottom should be machined.

b, The molds are filled in 3 increments and each increment is rodded 25 strokes with a ⅝-in. steel rod.

c, Within 2 to 4 hours after molding the cylinders should be capped with neat cement paste. Picture shows cement paste heaped upon top of the concrete, ready to be covered with the plate shown in next picture.

d, Plate is then pressed down until contact is made with the mold. Plate is left in place until forms are removed.

e, Sometime between 20 and 48 hours after molding, the forms are removed and the cylinders placed in storage. A convenient method of removing the forms is shown in this and the next picture. Place cylinder on pedestal which is approximately 12 inches high, as shown.

f, Open clamp and mold will drop of its own weight. If cylinder molds are stripped upward, the cap is often damaged.

Press a piece of plate glass or a machined plate down on the cement paste until the plate touches the cylinder mold. The plate should be

oiled first or a piece of waxed paper inserted between the paste and the plate.

Some engineers remove the cylinders from the moist storage 24 hours before breaking and cap with plaster of Paris or a quick-hardening cement. If dental plaster of Paris is used the cylinders may be tested within 5 min. after the cap is placed. The method outlined in the preceding paragraph is standard now and is being used by most laboratories.

11. *Curing.*—All cylinders should be cured in the same manner. For laboratory work a moist room is probably the most convenient. Storage in water or damp sand is just as satisfactory but much less convenient.

Remove the cylinders from the forms 20 to 48 hours after molding. Mark each specimen for identification later on. The specifications also provide for weighing the specimens. Place cylinders in moist room.

The temperature of the curing room should always be within the range of 18 to 24°C. (60 to 75°F.). Most laboratories attempt to keep the temperature at 70°F. It is important to keep the temperature constant and within the range specified. Automatic control of the temperature is desirable.

12. *Testing.*—The specifications provide that the test specimens shall be loaded in a damp condition. Measure the length and average diameter, and weigh if desired.

The metal bearing plates of the testing machine shall be placed in contact with the ends of the test specimen. Cushioning materials shall not be used. The bearing block shall be adjustable and placed on top of the cylinder. The diameter of the bearing block must also be the same or slightly larger than that of the cylinder. Keep the upper or lower section of the bearing block in motion as the head of the testing machine is brought to a bearing on the test specimen.

The load should be applied uniformly and without shock. The moving head of the testing machine should travel at the rate of about 0.05 in. per minute when the machine is running idle.

Place the cylinder in the testing machine, being careful to center the specimen under the bearing block. Note the total load required to break the cylinder. Test all cylinders at age of 28 days.

Questions

1. Which water-cement ratio produced the greatest strength? What was the slump of that batch? On what kind of work can such consistencies be used?

2. Were the batches with water contents smaller than that giving maximum strength suitable for construction work? Why?

3. Were the batches with water contents greater than that giving maximum strength suitable for construction work?

4. What is the difference between the high and low strength values?

5. Plat values strength against water-cement ratio. Plat Abrams' curve $S = 14{,}000/7^{z}$. How do the test values compare with the theoretical ones?

DATA RECORD—TEST NO. 31

EFFECT OF AMOUNT OF MIXING WATER ON THE COMPRESSIVE STRENGTH OF CONCRETE

For a Given Mix

Mix by volume 1 : 3 : 4, 4

Batch: Cement, 6,000 g.

Sand, 18,000 g.

Coarse aggregate, 26,400 g.

Time of mix, 2 min.

Date cylinders made, Nov. 5, 1928

Date cylinders broken, Dec 3, 1928

Age at breaking, 28 days

Batch number	Cylinder numbers	Water-cement ratio	Volume mixing water c.c.	Consistency		Strength, pounds per square inch
				Slump	Flow	
1	1-3	0.6	2400	0	130	1000
2	11-1	0.7	[illegible]	[illegible]	[illegible]	[illegible]
3	2-1	0.8	[illegible]	[illegible]	[illegible]	[illegible]
4	10-12	0.9	[illegible]	2	125	[illegible]
5	13-15	1.0	[illegible]	[illegible]	170	[illegible]
[illegible]	[illegible]	1.1	[illegible]	[illegible]	215	[illegible]
[illegible]	[illegible]	1.2	[illegible]	7	250	[illegible]
[illegible]	[illegible]	1.4	[illegible]	[illegible]	—	[illegible]

Cylinder number	Cylinder data			Compressive strengths		
	Diameter	Length	Weight	Total load, pounds	Average load, pounds	Average unit load, pounds per square inch
1	6"	12"		26 000	920	
2				33 000	1130	
3				32 000	1100	
4				37 000	1315	
5				41 000	1480	1375
6				43 000	1540	
7				—	—	
8				51 000	1840	1710
9				57 000	2040	
10				42 000	1490	
11				63 000	2250	2090
12				60 000	2140	
13				55 000	1960	
14				85 000	3015	2800
15				77 000	2750	
16				87 000	3110	
17				96 000	3430	3190
18				88 000	3140	
19				76 000	2710	
20				72 000	2570	2390
21				68 000	2430	
22				53 000	1910	
23				52 000	1870	1790
24				53 000	1910	

TEST NO. 32

EFFECT OF THE AMOUNT OF MIXING WATER ON THE COMPRESSIVE STRENGTH OF CONCRETE FOR VARIOUS WATER- CEMENT RATIOS AND UNIFORM CONSISTENCY

Object

1. To show the effect of the amount of mixing water on the compressive strength of the concrete, when the ratio of water to cement is varied and the consistency of the various batches is kept uniform.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates
Standard tamping rod
Slump cone (and flow table)
Compression testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. In this problem the ratio of water to cement will be varied and the consistency will be kept constant by varying the amount of aggregate used.

Decide upon a gradation of aggregate to use with each water-cement ratio. A suitable gradation is one in which the volume of coarse aggregate is one and three-fourth times the volume of fine aggregate.

3. *Water-cement Ratios.*—Vary the water-cement ratios from about 0.5 to 1.2, using as many as time and equipment will permit.

4. *Quantities of Materials.*—It will be practically impossible to estimate the amount of aggregate to mix with each water-cement ratio. It is suggested that the water-cement ratio from the preceding problem which gave the desired consistency be used as the basis for determining the tentative quantities. The lower water-cement ratios will require less aggregate and the higher ones more aggregate.

5. *Mixing.*—Coat the inside of the mixer with mortar. Weigh out the cement and water which are estimated, and place in the mixer. Place in the mixer also a quantity of aggregate which it is estimated will not be quite sufficient. Start mixer. After about ¾ min. it will be possible to determine the consistency approximately. If the mix is too wet add more aggregate, keeping the proportion of fine and coarse the same as originally planned. If the mix is too dry add more water

and cement keeping the ratio the same as before. Adjust until the desired consistency is secured.

In order to facilitate the work, it is desirable to have several small increments of aggregate weighed out ahead, so that the mixing need not stop for more than the fraction of a minute. The first batch will probably consume the most time in getting the proper consistency. Mix all other batches the same length of time.

Record the amounts of materials used in each batch.

6. *Consistency Tests.*—Make consistency tests on each batch.

7. *Molding, Capping, Curing, and Testing.*—Mold the cylinders, cap, cure, and test as prescribed in the preceding problem.

Questions

1. Plat values of strength against water-cement ratio on same sheet with those from test No. 31. How do the values secured in this test compare with those secured in the previous test? With the theoretical values?
2. What explanation is there for any variations?

DATA RECORD—TEST NO. 32

EFFECT OF THE AMOUNT OF MIXING WATER ON THE COMPRESSIVE STRENGTH OF CONCRETE FOR VARIOUS WATER-CEMENT RATIOS AND UNIFORM CONSISTENCY

Cylinders made, _____

Cylinders tested, _____

Age at testing, _____ days.

Specific Weights:

Cement, _____ g./cc.

Sand, _____ g./cc.

Pebbles, _____ g./cc.

Water-cement ratio	Batch—weights—grams				Mix by volume	Slump, inches	Cylinder numbers	Strength, pounds per square inch
	Water	Cement	Sand	Pebbles				

Cylinder number	Cylinder data			Compressive strengths		
	Diameter	Length	Weight	Total load, pounds	Average total load, pounds	Average unit load, pounds per square inch

TEST NO. 33

EFFECT OF AGE UPON COMPRESSIVE STRENGTH OF CONCRETE

Object

1. To show the effect of age upon the compressive strength of concrete.

Concrete gains strength with age. This problem is designed to establish that relationship for any given set of materials and conditions. The quality of the cement will affect the rate of hardening, the special cements gaining strength faster and gaining greater strength than the standard brands. Concretes with lower water-cement ratios will gain more strength at a faster rate than will those with higher water-cement ratios. Temperature will also affect the rate of gaining strength.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates (at least three molds and six plates for each batch of concrete)
Standard tamping rod
Slump cone (and flow table)
Compression testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. It is recommended that Test No. 34 be done at the same time, thus securing some data on the relationship between compression and beam test results. Since Test No. 34 is made on pavement concrete only, the mix in this case should be a 1:2:3 or a 1:2:3½. A water-cement ratio of 0.8 will generally be found satisfactory.

Cylinders may be tested at any ages desired. The following ages are suggested: 1, 3, 5, 7, 14, and 28 days. Testing at 3 months and 1 year is also recommended whenever time will permit.

3. *Size of Batch.*—Since all of the concrete is to be alike, the quantity mixed at one time may be as much as the mixer will accommodate. Determine the weights of each material per batch.

4. *Mixing.*—Mix all batches the same length of time. Coat the inside of the mixer with mortar first.

5. *Consistency Tests.*—Make the usual consistency tests as outlined in Test No. 31. Determinations on only one batch should be sufficient since all are alike.

6. *Molding.*—Follow the method of molding given in Test No. 31. Place a layer of concrete in each mold before depositing the second layer in any of the molds. In this way concrete from several batches will be placed in each cylinder and any variations in one batch will not appear in a small group of cylinders.

7. *Capping, Curing and Testing.*—Cap, cure, and test as outlined in Test No. 31, except that the age at testing should be as determined for this test.

Questions

1. Based on the Slater formula, what is the estimated 28-day strength of the concrete based on the 7-day value? How does this value compare with the value actually secured?
2. Plat curve showing relation between age and strength.
3. Consider 28-day strength as 100 per cent and figure percentages for other ages.
4. What factors enter in to influence the rate at which concrete gains strength?

DATA RECORD—TEST NO. 33

EFFECT OF AGE UPON COMPRESSIVE STRENGTH OF CONCRETE

Mix by volume 1:2:3

Water-cement ratio 0.8

Batch: Cement 15,000 g.

Sand 36,000 g.

Pebbles [illegible] g.

Water [illegible] g.

Time of mix 2 min. min.

Date cylinders made 11/12/28

Slump 3 3/4 in

Flow 190

Age, days	Cylinder numbers	Strength, pounds per square inch
1	1—3	[illegible]
3	4—6	[illegible]
5	7—9	[illegible]
7	10—12	[illegible]
14	[illegible]	[illegible]
21	[illegible]	

Cylinder number	Cylinder data			Compressive strengths		
	Diameter	Length	Weight	Total load, pounds	Average total load, pounds	Average unit load, pounds per square inch
						340
5						
1						1850
11						
12					4,3	2985
13				110,0		
14						
15						3870
16						
17						
18						

TEST NO. 34

EFFECT OF AGE UPON THE BEAM STRENGTH OF CONCRETE

Object

1. To determine the relationship between age and beam strength for a given concrete. Obviously the concrete will gain in beam strength the same as it does in compression. The chief value in doing this test is to get the values for a given concrete at the different ages. It is suggested that this test be made at the same time as Test No. 33, the *Effect of Age upon the Compressive Strength of Concrete.* If time permits several series might be run in which different cements or water-cement ratios are used.[1]

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Beam molds
Standard tamping rod
Slump cone (and flow table)
Beam testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. Since the practical application of this test is in connection with pavement concrete, it is suggested that one of the pavement mixes be used. Mixes generally used for pavements are the 1:2:3 or 1:2:3½, and occasionally the 1:1½:3.

If this test is made in connection with Test No. 33, the same mix and water-cement ratio should be used in both cases. Since all of the concrete is to be alike, the quantity mixed at one time may be as much as the mixer will accommodate. Mix all batches the same length of time. Make the usual consistency tests on concrete from one of the batches.

Place the first layer in all of the forms before starting on the second layer. Compact the concrete in the beam forms by spading with a regular concrete spading tool. Smooth off the surface of the concrete flush with the top of the form as soon as the concrete has set sufficiently.

3. *Curing.*—Remove beams from the forms at the same time the cylinders are removed for Test No. 33. Place in moist room until tested.

---

[1] The author has made it a practice to use different cements or water-cement ratios in the various classes each term and then to give all the results to each student.

4. *Testing.*—The same ages for testing are recommended as given for Test No. 33, namely, 1, 3, 5, 7, 14, 28 days. Apply the load and note the value when the beam breaks. Compute the modulus of rupture for each age. See the chapter on Testing for a sample of the computations.

Questions

1. Plat curve showing relationship between modulus of rupture and compressive strength.
2. Consider 28-day strength as 100 per cent and figure percentages for other ages. Compare values here with those for question 3 of test No. 33.
3. Figure ratio between modulus of rupture and compressive strength for each age. What is the average value and the maximum variation of any individual result from the average?
4. Would the shape or surface condition of the aggregate affect the modulus of rupture of value? In what way?

DATA RECORD—TEST NO. 34

EFFECT OF AGE UPON BEAM STRENGTH OF CONCRETE

1. Mix by volume, 1:2½:3
2. Water-cement ratio, 0.6
3. Batch: Cement, 15,000 g.
   Sand, 36,000 g.
   Pebbles, 52,500 g.
   Water, 9,000 g.
4. Time of mix, 2 min.
5. Date beams made, 11/12/28
6. Slump, 3.75 in.
7. Flow, 190
8. Cross-section of beam 6 x 6 in.
9. Moment of inertia ($\frac{1}{12}bd^3$), 108 in.^{3}
10. Distance extreme fiber to neutral axis (c), 3 in.
11. Weight of extension arm, ——— lb.
12. Distance center of gravity of extension arm to support, ——— in.
13. Moment extension arm, ——— in. lb.
14. Length of overhanging concrete, ——— in.
15. Moment of overhanging concrete, ——— in. lb.
16. Total moment of overhanging concrete and extension arm, ——— in. lb.
17. Stress in concrete due to overhanging concrete and extension arm, ——— pounds per square inch
18. Distance from support to load applied at end of extension arm, 36 in.

Age, days	Break numbers	Modulus of rupture, pounds per square inch
1	1–3	
3	4–6	475
5	7–9	15
7	10–12	725
14	13–15	765
28	16–18	

Break number 1	For loads applied at end of extension arm				Modulus of rupture, pounds per square inch 6
	Individual load, pounds 2	Average, pounds 3	Moment, ~~pounds per square inch~~ 4	Stress, pounds per square inch 5	

Modulus of rupture equal to values in column 5 and item 17 above.

TEST NO. 35

EFFECT OF CURING CONDITION UPON THE COMPRESSIVE STRENGTH

Object

1. To show the effect of various methods of curing on the compressive strength of the concrete.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates (at least three molds and six plates for each batch of concrete)
Standard tamping rod
Slump cone (and flow table)
Compression testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. Concrete strengths may be increased appreciably by proper methods of curing. Moisture is essential in curing concrete and the temperature affects the rate of hardening. These items may be checked in several ways in this problem. The following curing conditions are suggested with the idea that certain ones will be chosen or others added depending upon time and equipment:

One day in the forms and the balance as follows:

1. Twenty-seven days in the moist room
2. Twenty-seven days under water
3. Twenty-seven days in ordinary air temperature but without any moisture.
4. Ten days moist and balance of 28 days in ordinary air temperature. (This is a condition found on many jobs.)
5. Curing at temperatures other than those prescribed for laboratory and moist room. Cylinders might be placed outdoors in freezing weather to get the effect of freezing temperatures, or the cylinders might be placed in a refrigerator which can be controlled to any temperature desired

3. *Proportions.*—It is suggested that the same mix be used as in Test No. 31 and that the water-cement ratio be that which produced a fairly stiff consistency.

4. *Quantities of Materials.*—Since all of the concrete is to be alike, the quantity mixed at one time may be as much as the mixer will accommodate. Determine the weights for each batch.

5. *Mixing.*—Mix all batches the same length of time. It would be better if the time of mix in all of the concrete tests be uniform. A mixing time of 2 min. is suggested.

6. *Consistency Tests.*—Make the usual consistency tests on concrete from one of the batches.

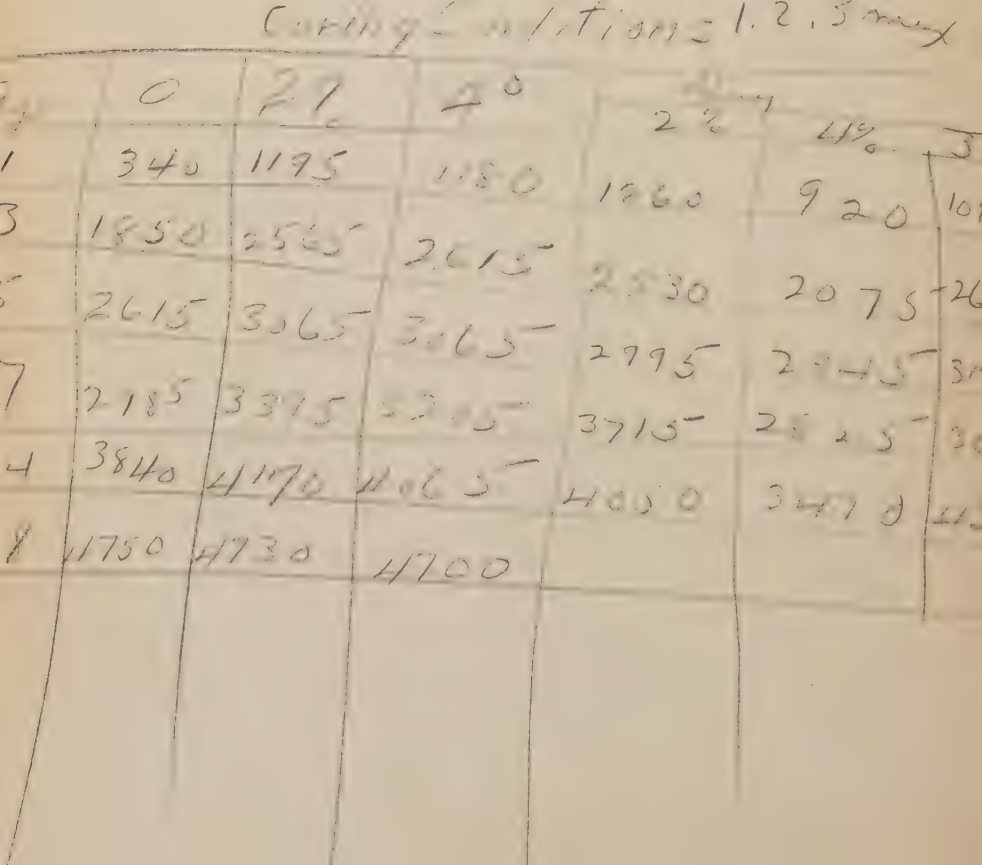
7. *Molding, Capping, Curing, and Testing.*—Mold, cap, cure, and test as previously prescribed in Test No. 31. Put first layer in all of the molds before placing the second increment in any.

Questions

1. How do the 28-day strengths for the various methods of curing compare?

2. Consider the case where the concrete is permitted to dry out as soon as placed. Strength tests are made at 7 days in order to estimate the probable 28-day strength from the Slater formula. Is the formula applicable? Why? How will the test values compare with the estimated values?

3. What factors during the curing period affect the strength of the concrete?



DATA RECORD—TEST NO. 35

EFFECT OF CURING CONDITIONS UPON COMPRESSIVE STRENGTH

Mix by volume, 1:2:3

Water-cement ratio, 0.8

Batch: Cement, 18,000 g.

Sand, 43,200 g.

Pebbles, 60,840 g.

Water, 9600 g.

Time of mix, 2 min.

Date cylinders made, 11/19/28

Date cylinders broken, _____

Slump, 7"

Flow, 175

Curing condition	Cylinder numbers	Strengths, pounds per square inch
Blank		

Universal P.C.

Compressive 4%

Cylinder number	Cylinder data 2% Cl₂			Compressive strengths 6% Cl₂		
	Diameter	Length	Weight	Total load, pounds	Average total load, pounds	Average unit load, pounds per square inch
1	33,000			34,...		
2	32,...			32,...		
3	55,000	33,700	1175	...	33,5...	1175
4	73,000			72,...		
5	70,000			73,...		
6	75,...	72,700	2563	72,...	74,...	2615
7	...			71,...		
8	70,...			...		
9	...	...	3065	80,...	83,700	3015
10	...			...		
11	...			...		
12	...	...	...	...	83,700	3215
13	...			116,...		
14	117,...			116,...		
15	120,...	117,...	4...	113,...	115,000	4065
16	132,...			133,000		
17	127,...			123,...		
18	129,...	124,...	4...	123,...	123,...	4700

Cured in moist room.

TEST NO. 36

EFFECT OF TIME OF MIXING UPON THE COMPRESSIVE STRENGTH OF CONCRETE

Object

1. To show the effect of the time of mixing upon the compressive strength of concrete. It is generally considered that increasing the time of mixing increases the compressive strength of the concrete.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates
Standard tamping rod
Slump cone (and flow table)
Compression testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. For this problem it is suggested that batches be mixed 20, 40, and 60 sec., and 2, 3 and 5 min. Most specifications call for a 1-min. mix and some are requiring 1½ or 2 min.

3. *Proportions.*—It is suggested that the same mix and water-cement ratio be used as in Test No. 31.

4. *Quantities of Materials.*—Determine the quantities of materials necessary to make the desired number of cylinders.

5. *Mixing.*—Place all of the materials for one batch in the mixer before starting. When the proper time of mixing has elapsed discharge concrete from the drum.

6. *Consistency Tests.*—Make usual consistency tests on each batch.

7. *Molding, Capping, Curing, and Testing*—Mold, cap, cure, and test as previously prescribed in Test No. 31.

Questions

1. Plat curve showing relationship between time of mixing and compressive strength.

2. Are the test results in accordance with the commonly accepted ideas?

3. What effect does increased mixing have upon workability? Upon the amount of mixing water necessary to produce a given consistency?

Data Record—Test No. 36

Effect of Time of Mixing upon the Compressive Strength of Concrete

Proportions by volume, _____

Water-cement ratio, _____

Batch: Cement, _____ g.

Sand, _____ g.

Pebbles, _____ g.

Water, _____ g.

Date cylinders made, _____

Date cylinders broken, _____

Time of mix minutes	Cylinder numbers	Slump	Strength, pounds per square inch

Cylinder number	Cylinder data			Compressive strengths		
	Diameter	Length	Weight	Total load, pounds	Average total load, pounds	Average unit load, pounds per square inch

TEST NO. 37

EFFECT OF GRADATION OF THE AGGREGATE UPON THE WORKABILITY AND YIELD OF CONCRETE

Object

1. To study the effect of gradation of the aggregate upon the workability and yield of the concrete.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates (at least three molds and six plates for each batch of concrete)
Standard tamping rod
Slump cone (and flow table)
Compression testing machine
Large pan or wheelbarrow for mixed concrete
Large trowel

Method

2. There are many problems which might be done under the title *Effect of Gradation of the Aggregate upon the Workability and Yield of Concrete.* Each individual or class must select for himself or themselves just what to do. The author has found the following problem very interesting for his classes.

Select some water-cement ratio and keep it constant throughout the series of tests. Vary the gradation of the aggregate and the proportions to correspond to give concrete of nearly uniform consistency. Several of the batches suggested are not workable so that it is not possible to have them of the same consistency as the workable batches.

The following gradations of aggregate are suggested:

1. All sand.
2. One part sand, 1 part coarse aggregate.
3. One part sand, 1½ parts coarse aggregate.
4. One part sand, 2 parts coarse aggregate.
5. One part sand, 3 parts coarse aggregate.
6. All coarse aggregate
7. One part sand, 2 parts coarse aggregate graded ¾ in. to 1½ in.
8. Batch 7 readjusted in the amount of coarse aggregate to give a workable mix.

The sand should be well-graded between 100-mesh sieve and the ¼-in. sieve. The coarse aggregate for the first six batches should be well-

graded between ¼ and 1½ in. In the last 2 batches the coarse aggregate should have the smaller sizes removed. Batch 7 will be unworkable because of an insufficient amount of mortar. In batch 8 the same amount of water, cement, and fine aggregate should be used but the amount of coarse aggregate reduced to give a workable concrete.

Before making the concrete for this problem, it is desirable for each student to plat the sieve analysis curves for the aggregate to be used in each batch. The sheet with these curves can then be incorporated in the formal report.

3. *Quantities of Materials.*—The same amount of cement and water is to be used in each batch. The amount of aggregate is to be varied each time in order to give the desired consistency. Batches 5, 6, and 7 probably will not be workable. These batches are included for the purpose of demonstrating what happens when such gradations are used.

It is suggested that 6,000 g. of cement be used and that the water-cement ratio be 0.9. It will be impossible to estimate the exact amount of aggregate to use in each case. In order to facilitate the work, it will be found convenient to weigh out in some small pans both sand and coarse aggregate in amounts of 500, 1,000, 2,000 and 5,000 g. The mix can be quickly adjusted while the mixer is running to give the proper consistency of the concrete.

4. *Mixing.*—Coat the inside of the mixer first with mortar.

5. *Batch* 1.—Place the water and cement for the first batch in the mixer. Add sand from a weighed supply until the mix is of the desired consistency. Determine weight of sand used. Note the length of mixing time. It should not be less than 2 min. since that amount of time will be needed in some of the other batches. Empty all of the concrete out of the mixer.

6. *Batch* 2.—Place in the mixer the water and cement for the second batch. Add aggregate until the mix is of the desired consistency. Equal parts by weight of sand and coarse aggregate should be added each time. The total weight of aggregate will be greater than in batch 1. Determine the amount of aggregate used. Mix same length of time as for batch 1.

7. *Batch* 3.—Place in the mixer the water and cement for the third batch. Add aggregate until the mix is of the desired consistency. The weight of coarse aggregate should be one and one-half times as much as the weight of sand each time. Determine weight of aggregate used.

8. *Batches* 4 *to* 8.—Repeat same procedure for remainder of the batches. In batch 8 put into the mixer the same amount of water, cement and sand as in batch 7. Then add the same coarse aggregate until the concrete is of the desired consistency. Note the amount of aggregate used.

9. *Consistency Tests.*—Make the desired consistency tests on each batch. If any of the batches are not of the desired consistency it might be well to repeat them.

10. *Molding, Capping, Curing, and Testing.*—Mold, cap, cure, and test as outlined in Test No. 31.

Questions

1. Which batch produced the most concrete? How does the amount of concrete produced compare with the batches in which the amount of coarse aggregate is one, one and one-half and two times as much as the fine aggregate?

2. How does the workability of the various batches compare?

3. How does the strength of the concrete in the various batches compare? Are the test results in accordance with the generally accepted ideas about concrete strength?

4. Considering yield, workability, and strength, which ratio of coarse to fine would you choose for a reinforced concrete job?

5. Figure quantities of materials per cubic yard of concrete for each batch. Use the unit weights of the materials as determined in test No. 11. Tabulate computations and results.

DATA RECORD—TEST NO. 37

EFFECT OF GRADATION OF THE AGGREGATE UPON THE WORKABILITY AND YIELD OF CONCRETE

Water-cement ratio, 0.9

Weight of cement used in each batch, 6,000 g.

Weight of water used in each batch, 3,600 g.

Time of mix, 2 min.

Date cylinders made, 12/10/28

Date cylinders tested, 1/7/29

Batch number	Weights, grams		Mix	Slump, inches	Volume of concrete produced	Strength, pounds per square inch
	Sand	Pebbles				
1						
2						
3						4600
4						4300
					4	3480

Cylinder number	Cylinder data			Compressive strengths		
	Diameter	Length	Weight	Total load, pounds	Average total load, pounds	Average unit load, pounds per square inch

TEST NO. 38

DETERMINATION OF THE WEARING QUALITIES OF A GIVEN CONCRETE IN THE TALBOT-JONES RATTLER

Object

1. To determine the wearing qualities of a given concrete as measured in the Talbot-Jones rattler.

Apparatus

Scales (100-kg. capacity)
Pans for weighing materials
Small concrete mixer
Cylinder molds and plates (two plates are necessary for each cylinder).
Molds for wear blocks (10 blocks constitute a set)
Standard tamping rod
Slump cone (and flow table)
Compression test machine
Talbot-Jones rattler
Large pan or wheelbarrow for mixed concrete
Large trowel

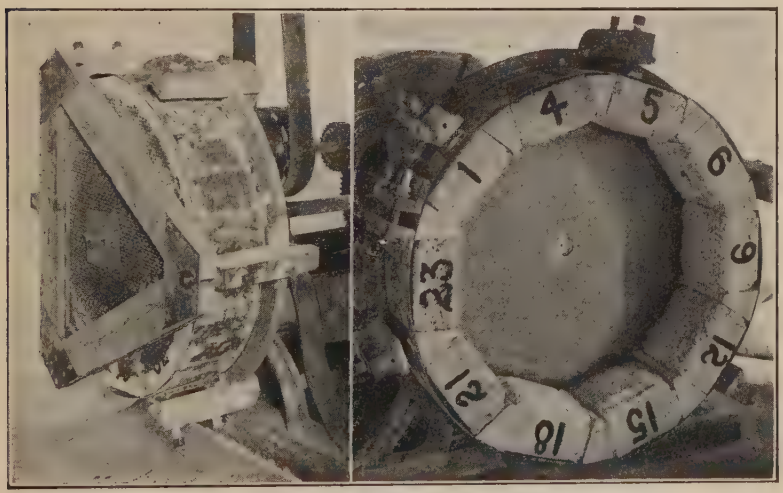


FIG. 1.—Wear test. *Left*, specimens in place and end of cylinder closed. *Right*, specimens in machine at end of test.

Method

2. The concrete to be tested is molded into 10 blocks, 8 by 8 by 5 in. These blocks are placed around the circumference of the drum of the Talbot-Jones rattler. A charge of 200 lb. of the spheres from the brick rattler is placed in the drum and run for 1,800 revolutions. This test has not been standardized in any way, so that the procedure given

is that which is generally followed in making the test. Make three cylinders in order to get the compression value for this concrete.

3. *Proportions.*—Since practically only pavement concrete is subjected to wear, it is suggested that the concrete for this problem be the same as that used in Probs. 33 and 34.

4. *Quantities of Materials.*—Determine the quantity of concrete necessary to fill the 10 molds and 3 cylinders. Determine the quantities of materials for each batch.

5. *Mixing.*—Mix all batches the same length of time. Coat the inside of the mixer first with mortar made of the same proportions as that which is in the concrete.

6. *Consistency Tests.*—Make a consistency determination on the concrete from one of the batches.

7. *Molding.*—Mold the cylinders in the standard manner. Fill the wear block forms in two increments rodding each increment 25 times with the standard rod. Smooth off the surface flush with the top of the form.

8. *Curing.*—The method of curing will affect the wearing value secured even though it may not effect the compressive strength. It is suggested that the blocks be covered with wet burlap as soon as finished. After 20 to 48 hours remove from the molds and cure as desired.

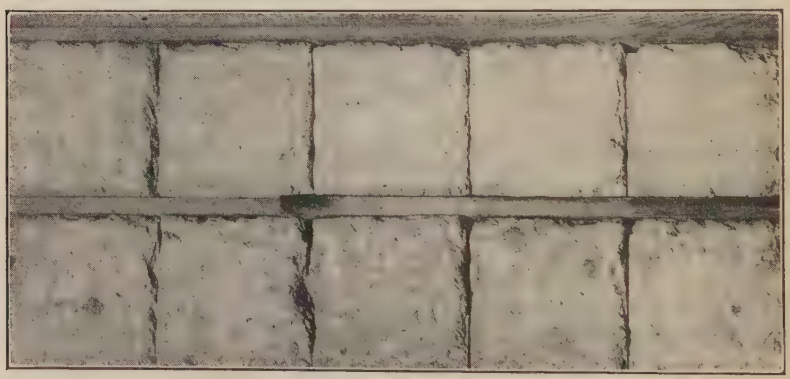


FIG. 2.—Some tested wear block specimens.

9. *Testing.*—Weigh blocks collectively unless any individual variations are to be noted. Fit the blocks around the circumference of the drum of the Talbot-Jones rattler. Insert wedges between the blocks to hold them securely in place. Fasten the piece of heavy woven wire over the end of the cylinder.

The abrasive charge consists of the 10 large spheres and enough of the smaller ones from the brick rattler to make a total weight of 200 lb. Place charge in the cylinder through the opening in the woven wire.

Run for 1,800 revolutions at a speed of 30 to 33 r.p.m. Remove the blocks and weigh.

10. *Wear Value.*—The wear value is expressed as the number of inches worn away during the test. It is equal to

$$\frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times \text{initial depth of blocks}$$

11. *Compression Test.*—Test the cylinders in compression in same manner as given in Test No. 31.

Questions

1. What is the general relationship between strength and wear?
2. The above relationship is based on tests made at what ages? Are compressive tests made at early ages, such as 3, 5, or 7 days indicative of the wearing qualities of the concrete? Why?

Data Record—Test No. 38

Determination of Wearing Qualities of a Given Concrete in the Talbot-Jones Rattler

Mix by volume, _____

Water-cement ratio, _____

Batch: Cement, _____ g.

Sand, _____ g.

Pebbles, _____ g.

Water, _____ g.

Slump, _____ in.

Initial weight 10 blocks, _____ g.

Final weight 10 blocks, _____ g.

Loss, _____ g.

Wear value, _____ in.

Date specimens made, _____

Date specimens tested, _____

Crushing strength of cylinders, 1. _____

2. _____

3. _____

Average _____

REPORT
CEMENT

Brand					
Specific gravity, 25°C.					
Fineness, per cent retained					
Normal consistency, per cent					
Soundness					
Time of setting,	Gillmore needles				
	Vicat apparatus				
Tension tests	7 days				
	28 days				
Compression tests	7 days				
	28 days				

Comments:

REPORT

FINE AGGREGATE

Material				
Specific Gravity, 25°C.				
Weight, lb./cu. ft.				
Weight, g./cc.				
Voids, per cent				
Surface moisture, per cent				
Silt, loam, clay, etc., per cent				
Organic impurities test				
Tension Tests	S.O.S.	7 days		
		28 days		
	Test Sand	7 days		
		28 days		
Compression Tests	S.O.S.	7 days		
		28 days		
	Test Sand	7 days		
		28 days		
Bulking			see curve	
Sieve analysis per cents passing				
Fineness Molduus				

REPORT
COARSE AGGREGATE

Material			
Specific gravity, 25°C.			
Weight, lb./cu. ft.			
Weight, g./cc.			
Voids, per cent			
Soundness			
Sieve analysis per cents passing			
Fineness Modulus			

Comments:

Conversion Factors

Relation between Temperatures Centigrade and Fahrenheit.

$$\text{Temperature degrees Fahrenheit} = \tfrac{9}{5}°\text{C.} + 32$$

$$\text{Temperature degrees Centigrade} = \frac{5(°\text{F.} - 32)}{9}$$

English Metric Conversion Factors.

453.6 grams	= 1 pound
2.205 pounds	= 1 kilogram
28.35 grams	= 1 ounce
0.03527 ounce	= 1 gram
25.4 millimeters	= 1 inch
2.54 centimeters	= 1 inch
0.03937 in.	= 1 millimeter
0.3937 in.	= 1 centimeter
3.281 feet	= 1 meter
2.113 pints	= 1 liter
3.785 liters	= 1 gallon
16.39 cubic centimeters	= 1 cubic inch
28320 cubic centimeters	= 1 cubic foot
0.610 cubic inch	= 1 cubic centimeter
0.00003351 cubic foot	= 1 cubic centimeter

APPENDIX B

List of A. S. T. M. Standards and Tentative Standards Relating to Concrete and Concrete Materials

Serial Designation	Standards
C9-26	Standard Specifications and Tests for Portland Cement
C29-27	Standard Method of Test for Unit Weight of Aggregate for Concrete
C30-22	Standard Method of Test for Determination of Voids in Fine Aggregate for Concrete
C31-27	Standard Methods of Making and Storing Specimens of Concrete in the Field
C39-27	Standard Methods of Making Compression Tests of Concrete
C40-27	Standard Method of Test for Organic Impurities in Sands for Concrete
C41-27	Standard Method of Test for Sieve Analysis of Aggregates for Concrete
C24-24	Standard Method of Securing Specimens of Hardened Concrete from Structures
D2-26	Standard Method of Test for Abrasion of Rock
D3-18	Standard Method of Test for Toughness of Rock
D30-18	Standard Method of Test for Apparent Specific Gravity of Coarse Aggregates
D55-25	Standard Methods of Test for Apparent Specific Gravity of Sand, Stone and Slag Screenings, and Other Fine Nonbituminous Highway Materials
D75-22	Standard Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials, Including Some Material Survey Methods
E4-27	Standard Methods of Verification of Testing Machines
E11-26	Standard Specifications for Sives for Testing Purposes
E12-27	Standard Definitions of Terms Relating to Specific Gravity
	Tentative Standards
C9-16T	Tentative Specifications and Tests for Compressive Strength of Portland Cement Mortars
C33-28T	Tentative Specifications for Concrete Aggregates
C58-26T	Tentative Definitions of the Terms Sand and Aggregate
C68-28T	Tentative Method of Test for Field Determination of Approximate Apparent Specific Gravity of Fine Aggregate
C69-28T	Tentative Method of Test for Field Determination of Approximate Percentage of Voids in Fine Aggregate

C70-28T Tentative Method of Test for Field Determination of Surface Moisture in Fine Aggregate

D98-22T Tentative Specifications for Calcium Chloride for Dust Prevention

D136-22T Tentative Method of Decantation Test for Sand and Other Fine Aggregates

D138-26T Tentative Method of Test for Consistency of Portland-cement Concrete

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6 in diam Eyebeams.

tch	total load lbs.	average Total Load lbs.	average Unit Stress lbs.	Unit in.
	64000 72000 75000	70,300	2480	
	110,000 108,000 104,000	107,700	3800	
	105,000 96,000 98,000	99700	3520	
	80,000 80,000 79,000	79,700	2820	
	71,000 70,000 72,000	71,000	2520	
	65,000 67,000 63,000	65,000	2300	
	32000 35000 39000	35,300	1250	
		3/101		

Beam
650
630
670

$$3 \overline{)211,000} \quad 70,333$$

21

$$3 \overline{)322} \quad 107\,300$$

$$3 \overline{)2997^{20}} \quad 996600$$